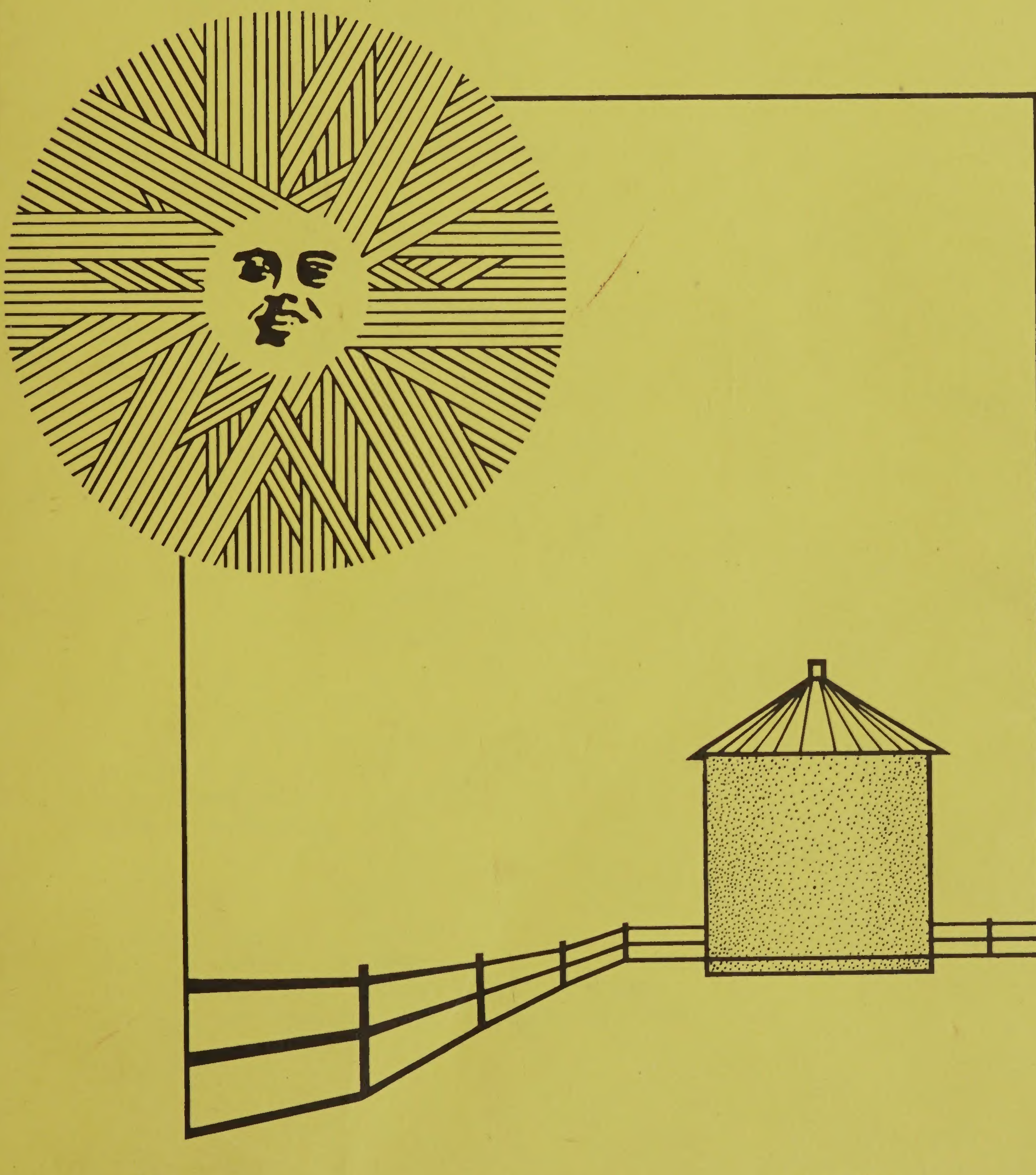
On-Farm Demonstration of Solar Drying of Crops and Grains



United States
Department of
Agriculture

PREPARED BY
Extension
Service

PREPARED FOR
United States
Department of
Energy

ON-FARM DEMONSTRATION OF SOLAR DRYING OF CROPS AND GRAINS

FINAL REPORT
MARCH 1983

Prepared by
U.S. Department of Agriculture
Extension Service

Prepared for
U.S. Department of Energy
Division of Solar Thermal Energy Systems
Interagency Agreement No. DE-AI01-80CS30459

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SUMMARY

The research, conducted by the U.S. Department of Agriculture (USDA) with pass-through funds from the Department of Energy (DOE), on the potential to replace fossil-fuel energy with solar energy in drying of crops was sufficiently encouraging so that DOE concluded that there should be an on-farm demonstration project of solar drying of crops and grains. This resulted in DOE's passing funds to Extension Service-USDA to conduct this program. Projects were established in nine different states with a total of 75 on-farm projects in the nine states.

The objectives of the program were to (1) demonstrate the technical and economic feasibility of using solar energy technology for drying systems to provide significant amounts of the heating requirement for on-the-farm crop and grain drying and other supplemental uses; (2) test, to the maximum extent possible, solar energy technology developed under DOE/USDA-SEA-ARS (Agricultural Research Service) program under operating farm conditions; (3) incorporate and utilize energy conservation techniques well known to the industry; (4) minimize the interruption or interference in the normal operation of the drying facilities; and (5) identify incentives and opportunities for widespread farm applications of solar energy technology.

Although the program was terminated approximately one year prior to the expected termination date, it has been worthwhile. The engineers involved in the projects have learned much in the area of design, construction, and operation of a solar system. Observations by the project managers will be continued on many of the projects; much additional information will be gathered; and additional educational efforts will be carried out.

A copy of each state report is included in Appendix B.

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FINAL REPORT
ON-FARM DEMONSTRATION OF SOLAR DRYING OF CROPS AND GRAINS

INTRODUCTION

The research conducted with pass-through funds from the Department of Energy (DOE) to the U.S. Department of Agriculture (USDA) indicated that a substantial amount of fossil-fuel energy could be replaced with solar energy in the drying of crops and grains. The findings from this research created interest by DOE in funding on-farm demonstration projects in the use of solar application in drying crops and grains. An interagency agreement, No. DE-AI01-80CS30459, was signed by DOE and Extension Service-USDA whereby DOE would pass funds to ES-USDA in the amount of 1.095 million dollars to conduct on-farm demonstrations in the area of drying crops and grains.

Subsequently, a competitive process was used to select states to conduct the demonstration projects. Initially, all states were invited to submit preproposals outlining what they would do and how they would proceed; also a proposed budget was required to accompany the preproposals. Preproposals were received in July 1980, and evaluated by a panel of engineers, architects, and economists. States whose preproposals were approved were invited to submit complete proposals. Twelve states were elected to submit proposals. Awards were made to nine states in December 1980. Those states were Florida, Illinois, Kansas, Maryland, Michigan, Missouri, South Carolina, Tennessee, and Virginia. Funding was made available to the states in February 1981, following the signing of Cooperative Agreements by ES-USDA and the nine states.

Although the initial timetable for this program allowed approximately one year to get the designs, construction, and initial testing completed and two years to evaluate the performance of the systems, it became necessary to terminate the program approximately one year early. Since some projects were running behind schedule, there was a lack of information on which the projects could be evaluated. Most projects have one year of data while some have not produced any data.

Even though the program was terminated early and the third-year funding from DOE did not materialize, the project managers generally plan to continue to gather data and further evaluate the projects - if they can obtain local funding to do so. It is suggested that for further information regarding any of the projects in the state report, the project manager for that specific project be contacted.

OBJECTIVES

The objectives of the program were to (1) demonstrate the technical and economic feasibility of using solar energy technology for drying systems to provide significant amounts of the heating requirements for on-the-farm crop and grain drying and other supplemental uses; (2) test, to the maximum extent possible, solar energy technology developed under the DOE/USDA-SEA-ARS program under operating farm conditions; (3) incorporate and utilize energy conservation techniques well known to the industry; (4) minimize the interruption or interference in the normal operations of the drying facilities; and (5) identify incentives and opportunities for widespread farm application of solar energy technology.

While these are the objectives of the overall program, each state has its own set of objectives. The states' objectives include the areas listed above, as well as objectives that are more specific to their own geographic locations. The states' objectives are included in the individual state reports in Appendix B.

PROCEDURE

The Cooperative Extension Service in all states were invited to submit preproposals outlining what they would do and how they would proceed. A panel of professionals evaluated the preproposals. The panel members were Walter E. Matson, Extension Service, USDA; Dean L. Spearman, Price Support and Loan Division, USDA; Benjamin R. Beckham, Farmers Home Administration, USDA; Gary Reisner, Economic Research Service, USDA; Gerald Kline, Agricultural Research Service, USDA; and Paul R. Barnes, Oak Ridge National Laboratory.

Of the 14 preproposals received, 12 were accepted and these 12 states were asked to submit proposals. Of the 12 proposals received, nine were selected for funding with DOE pass-through funds. The following criteria were used to evaluate both the preproposals and the proposals: quality of technical approach, potential cost effectiveness, scope of potential applications, plans for public exposure, adequacy of project management plan, and prior experience in solar energy application.

The nine states selected for inclusion in the program were: Florida, Illinois, Kansas, Maryland, Michigan, Missouri, South Carolina, Tennessee, and Virginia. Figure 1 is a map showing the location of the selected states. A three-year budget was submitted as a part of each proposal and a copy of the suggested format for the budget is included in Appendix A.

There is a total of 75 on-farm projects in the nine states. A classification of the projects is given in Table 1. There is overlapping of the classifications in most areas, indicating multi use and/or multi type of collectors used on a single project. The original plan called for approximately ten projects for each of the nine states. With the high interest rate on borrowed money and low farm prices, not to mention deaths and other unexpected events, several of the original participants discontinued their involvement in the projects. In some cases, a substitute participant could be located; thus, the final number, instead of being 90 projects, is 75 projects. The project managers in cooperation with the farmer participants completed the designs for the projects and submitted them to ES-USDA for approval prior to construction. ES-USDA established an advisory committee of knowledgeable people in the use of solar energy in agriculture to review the designs and make comments regarding the merits of the designs.

The Advisory Committee members were Stephen Kaplan, Oak Ridge National Laboratory; George H. Foster, Professor, Agricultural Engineering Department, Purdue University; Marvin D. Hall, Agricultural Engineer, University of Illinois; and Gerald L. Klein, Agricultural Engineer, ARS-USDA, Iowa State University. Many of the designs were reviewed at meetings at which the project managers could explain their project designs to the Advisory Committee and answer any questions. Other designs were reviewed by mail. The review meetings proved to be the more satisfactory method.

The ES-USDA coordinator for the program reviewed the results of the Advisory Committee review and wrote a letter of approval or disapproval to the project manager. Comments of the review committee members were included in the letters to the project managers. There followed an opportunity for the project managers to review and resubmit the disapproved designs for further consideration.

A portion of the funding for the state projects could be used to refund the farmer participant a part of his expenses for the solar addition to the project. Except in unusual circumstances, this could not exceed 50 percent of the total cost of the solar addition.

An agreement was drawn up between the Cooperative Extension Service of the University and the farm participant outlining the responsibilities of the parties involved. A suggested agreement format is included in Appendix A.

Necessary instrumentation was installed so that data could be collected to determine the actual solar energy collected by the system, the efficiency of the system, and the economic feasibility of the system. There was no set equipment or procedure established for data collection and analysis. It was the prerogative of the project manager to determine the instrumentation needed and the method of analyzing the data for these projects.

A review of the 75 projects (See Table 1) shows that there are 74 air collectors and 3 water collectors - a total of 2 more than the number of projects. Thus, two projects used both air and water collectors. One of these projects is located in Virginia where a water collector is used to collect solar energy for curing tobacco and an air collector is used to dry grains on the Roger Winn Farm. All 75 of the projects are used for crop drying - 12 different crops. In addition, 42 systems are used for space heating and 2 for domestic hot

water. Thus, 44 of the 75 projects are designed for multi use. Storage is included in eight of the projects. Thirty-one of the projects use portable collectors. The size of the portable collectors may be too large for easy mobility where the collectors are placed on skids instead of wheels.

Figure 1. The nine states that are included in the On-Farm Demonstration of Solar Drying of Crops and Grains

Table 1: Summary of the On-Farm Demonstrations

Solar Drying of Crops and Grains Projects

Cooperators 75

Solar Collectors

Transfer Media: Air 74

Water 3

Type of Structure: Portable 31

Stationary 46

1. Modified Trombe Wall 1
2. Roof 24
3. Attic 7
4. Free Standing 1
5. Other 28

Storage: Yes 8 No 67

Type:
1. Water 2
2. Rock 3
3. Modified Trombe Wall 1
4. Other 2

Use:

Space Heating 42
1. Residence 12
2. Shop 24
3. Swine 10
4. Dairy 3
5. Poultry 1
6. Other 4

Crop Drying 75
1. Hay 3
2. Fruit 2
3. Vegetables 2
4. Peanuts 9
5. Grain 35
6. Corn 52
7. Soybeans 29
8. Tobacco 3
9. Other 6

DHW 2
1. Residence 2

ECONOMIC EVALUATION

Generally, economic evaluation is incomplete since the program was terminated early. With one or less season's operation, it is difficult to have confidence in the results; so very much can depend on the weather for drying a crop. In many ways, this has influence on the solar systems as well as the crop. Also, because of many different assumptions that can be made regarding interest rate, depreciation, inflation, taxes and system life, an accurate economic evaluation is very difficult. However, these are some observations that can be made.

Illinois, for one of their projects, analyzed the economics three different ways: (1) Based on replacing $0.75 per gallon LP gas the simple payback was 14.9 years; (2) based on replacing $0.06 per KWH electric heat the simple payback was 7.0 years; and (3) based on the cost of drying corn in a solar bin versus cost of drying the same corn in a check bin showed a 4.5 year payback in 1981, and no payback for 1982.

In South Carolina, the preliminary design developed for their project proposal indicated that the only solar system that would be competitive with alternative fuels was a system of simple design, incorporating straightforward construction techniques so that farm labor could construct it out of readily available materials.

Solar drying offers alternative operational schemes for the farmer when seasonal demands, energy prices, and/or political decisions cause shortages of other fuels.

Table 2 in Virginia's report in Appendix B gives the results of using the solar crop drying units where an effective evaluation could be made. However, the project manager stated that units should not be compared since many variables may be reflected in the results. In some cases, two years of data give different results than when using only one year. For instance, solar drying, when used only for peanuts, showed approximately 30 percent savings in 1981 but somewhat less in 1982. Field drying conditions were more favorable in 1982 than in 1981; thus, the solar dryers were not needed as much in 1982.

Based on 1982 results, nine of the ten projects in Tennessee varied from 1.8 year simple payback to 36.7 years. Six of the nine projects had payback falling between 1.8 and 5.0 years.

Missouri used a 10 percent energy inflation per year and with no return on investment the payback ranged from 2.0 to 10.5 years for five of their seven projects; for a ten percent return on investment the range was from 2.5 to 20.0 years for the same five projects.

In Florida, the overall performance of several of the systems was classified as very successful. Two cooperators are very pleased and feel that they have received economic returns. Two other cooperators, whose designs utilized bare-plate collectors, did not feel the systems produced the amount of energy they had anticipated, although they were within the expected design performance. Performance of each system is given in the state's reports in Appendix B.

Of the Maryland projects, there were four that developed enough to determine that they have a potential for reasonable economic return to the farmer. The simple payback period for the farmer fell between 5.6 and 8.1 years. The evaluation does not consider such variables as alternative use of the collector, energy tax credits, inflation of the cost of fossil fuels, or improved efficiency with use of the system.

Kansas used a life-cycle economic analysis on each system to determine economic variability. The following economic parameters were used:

Economic life: 10 years
Salvage value: 10% of collector cost
Energy tax credit: 15% Federal, 30% State
Investment tax credit: 10%
Depreciation: Straight line (cost-salvage)/ 10 years
Type of fuel replaced: LPGas
Initial fuel cost: 65¢ per gallon
Fuel cost escalation rate: 10% per year
General inflation rate: 7% per year
Marginal income tax bracket: 25%
Property tax and insurance rate: 3% of collector cost per year
Maintenance costs: 1% of collector cost per year

Obviously, the economic parameters would vary with each solar dryer and farmer; however, by keeping them the same, economic comparisons may be made for each collector. The table on page 46 of the report from Kansas gives the Economic Rate of Return for each system based on the above economic parameters and one year collection of data. This of course does not give the economic variability over the life of the system. It was merely used as a tool for comparison.

In Michigan, an economic analysis program that had been developed using a hand-held programmable calculator to analyze the economics of solar hot-water heating was modified for use in determining break-even investment for solar collector units for crop drying. Eleven factors and assumptions plus certain recorded and measured information were used in calculating the break-even costs for solar facilities on which they reported. The range of break-even investment ranged from $0.40 to $0.72 per square foot for the least efficient system to $1.69 to $2.15 per square foot for the most efficient system. Details of the analysis are given in the state report in Appendix B. A list of seven conclusions is given on page 8 of the report.

EDUCATIONAL ACTIVITIES

Although most educational activities will occur after the systems have operated long enough to give confidence in the results, there have been some public relations and some educational activities carried out. Other activities are expected in the future providing funds can be obtained to finance them.

Illinois has published three Energy Tips, No. 7, 8, and 9, related to their projects. They have also published a plan which has been revised; over 5,000 copies of this plan have been distributed. They have had planned tours to two of the projects at which 70 people attended. They also had, in 1982, 12 workshops with 395 in attendance and a two-day conference with an attendance of 110. They plan, in 1983, to have a two-day conference and 18 workshops related to their projects.

In 1982, the South Carolina project manager held two tours at which approximately 90 people attended. They have also prepared a slide set and a film strip for use in meetings regarding the use of solar systems in agriculture.

In Virginia, the following educational activities have been carried out: Prepared a fact sheet series; drew plans of the demonstration designs; prepared fliers on each project to hand out at meetings and tours; given information for articles about the projects in newspapers, magazines, radio and television programs and made them available to agents for local use; held tours; had agent training; gave presentation at production meetings for farmers; and prepared exhibits for presentations within the state.

At the Tennessee projects, there have been six group tours with an attendance in excess of 165. Also, it is estimated that 25 individuals have visited each project. There have been nine newspaper articles and a magazine article on the demonstrations. The project manager has presented two papers at professional meetings. It is planned to prepare and publish five Fact Sheets related to the projects. Other future activities include continuing to monitor some of the installations, work with farmers, get additional newspaper articles, and encourage tours and field days.

In Missouri, a training session for Missouri Area Agricultural Engineering Specialists has been given on solar grain drying designs. Three programs for farmers and vocational agriculture Young Farmers groups have been held. A meeting has been scheduled for 1983 that consists of four sessions, each two hours in length.

Since the program is being terminated early, Florida's educational effort has been in the area of what was to be done and the expected performance. These efforts have included presentations at Extension training meetings, technical meetings, newspaper and magazine articles and television presentations. Signs have been erected at the project sites. Additional educational programs are planned. These include on-site visits and more detailed Extension publications. The individal project reports will be sent to each county in Florida.

In Maryland, many educational activities were conducted; however, without results from the demonstrations, most activities were in the area of information related to the projects. The activities include information to the Agricultural Extension Agents; radio, newspaper and newsletter publicity; news articles in the monthly Agricultural Engineering Newsletter; talks to farmer groups; and a feature article in The Delmarva Farmer which reaches nearly all farm homes in Maryland. Future activities will include tours and a series of publications to assist in planning, construction, operating, and managing low-temperature solar drying systems. A slide-tape set on low-temperature solar drying will be developed and presented throughout the state. A panel on solar drying will be included in a new farm energy exhibit.

In Kansas, educational activities include the presentation of information on solar grain drying through meetings, radio, newspapers, journals, energy fair and individual contacts. At the Kansas State Fair, solar collectors were used to demonstrate how different amounts of energy could be collected using different air-flow rates through identical collectors. Over 250 Midwest Plan Service publications on Low Temperature and Solar Grain Drying have been distributed in Kansas during the past two years.

In Michigan, three meetings are scheduled during the winter of 1983 at which the current results from their project will be discussed with agricultural producers.

The economic feasibility analysis will continue through the winter of 1983 under funding from the Cooperative Extension Service, Michigan State University.

GENERAL COMMENTS

Solar grain drying in the southeastern United States seemed at first to be an ideal operation. Some restrictions, however, that are not readily apparent are early corn harvest, beginning in July; annual rainfall of 50 to 60 inches per year; and overwintering of destructive grain storage pests.

Solar drying offers an alternative operating scheme for the farmer when seasonal demands, emergencies, or political decisions cause shortages of conventional fuels.

Overall, the program will promote the use of solar energy. In addition, these on-farm demonstration projects will give educators an opportunity to present additional programs on grain drying and storage to farmers who attend meetings on solar but not on grain storage. The "piggyback" potential is great.

The quality of the finished solar system construction varied from demonstration to demonstration depending primarily on the construction expertise and management skills of individual cooperators.

While a wide distribution of farm cooperators within a state was desirable so that they would be available to more farmers for visits, this requires extra travel and time for monitoring the projects.

This solar crop drying program has been successful from the standpoint of accomplishment, experience with operators, information dissemination, development of data collection system and potential for further solar energy application.

A solar system designed for crop drying and alternative uses should consider the requirements for each use. The air rates for crop drying are typically high while those used for space heating are low, although the temperature rise should be high for space heating.

Air ducts are either expensive with low heat loss or inexpensive with high heat losses. In either case, ducts have considerable influence on solar system economics. If they are small in diameter, their resistance to airflow is high; thus, fan operation is more expensive. Large ducts are, of course, more expensive.

There was a considerable number of cooperators who withdrew from state projects after having agreed to cooperate. Some of the reasons given include: (1) too much time between submission of proposed project and approval to begin construction, (2) high interest rate, (3) the fact that the farmer had to pay for the entire system "up-front", (4) state of farm prices and general economy, (5) energy availability and price, (6) second thoughts about low-temperature drying, (7) concern over payback, and (8) decision to spend funds on additional grain drying capacity rather than on solar system.

APPENDIX A

Suggested Format for Budget

Agreement Form Between State and Cooperator

Form for Cooperative Agreement Between the
Cooperative Extension Service and ES-USDA

BUDGET

ITEM	YEAR 1	YEAR 2	YEAR 3	TOTAL
I. ANNUAL COST				
II. SOURCE OF FUNDS				
University				
Farmer Cost Share				
ES-USDA				
TOTAL				
III. SALARIES				
(A) Professional				
Ex. Assistant				
FTE				
(B) Graduate Student				
Student Labor				
(C) Draftsman (FTE)				
(D) Secretarial (FTE)				
(E) Staff Benefits				
TOTAL				
IV. TRAVEL				
V. EQUIPMENT				
(A) Solar Equipment(1)				
(B) Instrumentation and Monitoring(2)				
TOTAL				
VI. SUPPLIES				
VII. OTHER				
Telephone and Copy Service				
Maintenance-Inst.				
TOTAL				

(1) Title to be vested with cooperating farmers at time of making cost share payment.

(2) Title to be vested with University of   at termination of project.

COOPERATIVE AGREEMENT
BETWEEN
THE COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF
AND
THE SCIENCE AND EDUCATION ADMINISTRATION-EXTENSION
UNITED STATES DEPARTMENT OF AGRICULTURE

I. Purpose

The purpose of this agreement is (1) to demonstrate the technical and economic feasibility of using solar energy technology for drying systems to provide significant amounts of the heating requirements for on-the-farm crop and grain drying and other supplemental uses; (2) to test, to the maximum extent possible, solar energy technology developed under the DOE/USDA SEA federal research program under operating farm conditions; (3) to incorporate and utilize energy conservation techniques well known to the industry; (4) to minimize the interruption or interference in the normal operation of the drying facility; and (5) to identify incentives and opportunities for widespread farm applications of solar energy technolgy.

II. Situation

USDA-ARS experimental solar crop and grain driers have shown the technical feasibility of providing a significant portion of the annual heating requirements by solar energy as a substitute for fossil fuel. Because fuel costs represent a significant amount of operational costs of crop and grain drying systems, the Department of Energy (DOE) is pursuing a vigorous program in the application of full-scale prototype systems on farms. Consequently, DOE has made one million dollars available to USDA-SEA-Extension to demonstrate the use of solar energy for on-the-farm drying of crops and grains. The projects were selected for the application of solar energy drying systems to crops, food and feed grain driers, oil seed driers, or others and based upon preproposals and full proposals submitted by the Cooperative Extension Services interested in the program. Each project is cost-shared and may consist of single or multiple buildings and single or multiple farm locations.

III. Agreement

It is agreed that the Science and Education Administration-Extension and the Cooperative Extension Service, University of   will cooperate for their mutual benefit in an effort (1) to demonstrate the technical and economic feasibility of using solar energy technology for drying systems to provide significant amounts of the heating requirements for on-the-farm crop and grain drying and other supplemental uses; (2) to test to the maximum extent possible solar energy technology developed under the DOE/USDA SEA federal research program under operating farm conditions; (3) to incorporate and utilize energy conservation techniques well known to the industry; (4) to minimize the interruption or interference in the normal operation of the drying facility; and (5) to identify incentives and opportunities for widespread farm applications of solar energy technology.

IV. Responsibilities of the Parties

A. Pursuant to this agreement, the Cooperative Extension Service will:

1. Demonstrate that simple, low cost solar collectors can provide significant amounts of heat energy for drying grain and hay.

2. Demonstrate that significant amounts of energy can be saved in comparison with gas or electric heat grain drying systems.

3. Demonstrate that solar collectors incorporated into the roofs and/or walls of machinery storage buildings and livestock shelters for the primary purpose of drying grain can also provide energy for heating livestock shelters and farm shops.

4. Demonstrate that free standing moveable solar collectors can be used for drying grain during the harvest season and then be moved to provide space heating during the winter.

5. Demonstrate that collectors attached to grain drying bins can be successfully applied to the drying of grain, particularly to low heat methods of drying.

6. Demonstrate the conditions or situation under which solar drying is economically competitive with conventional crop drying practices.

7. Make available to the Science and Education Administration-Extension copies of all materials developed as a part of this project.

8. Furnish progress reports as requested by the SEA-Extension Liaison Officer.

9. Provide SEA-Extension quarterly a statement of cost incurred by expenditure classification. The first report covers costs incurred through June 30, 1981, and is due in SEA-Extension 15 days after the end of the quarter.

B. Pursuant to this agreement the SEA-Extension will:

1. Authorize funds in the amount of   in an amendment to the letter of credit. Total cost to SEA-Extension under this agreement will not exceed   . All funds authorized are subject to the provisions of Section C-3.

2. Provide technical assistance and guidance as needed.

C. Pursuant to this agreement, it is mutually agreed that:

1. This agreement shall become effective on the date of the last affixed signature and shall remain in effect until September 30, 1981, unless extended by mutual consent.

2. This agreement may be terminated at any time by either party upon receipt of written notice 30 days in advance of the intended date of termination.

3. Should there be any unobligated funds remaining, at the conclusion of the project, such funds shall be refunded to the SEA-Extension and any undrawn authorization under the letter of credit revoked.

4. Provisions of the approved proposal on which this agreement is based that may not be explicitly stated herein, are considered an integral part of this agreement.

5. The cooperation of the SEA-Extension and the Cooperative Extension Service, University of , will be acknowledged on any material published as a result of work carried out under the terms of this agreement.

6. Attached hereto and made a part of this agreement are the provisions of Executive Order No. 11246, dated September 24, 1965, Sec. 202, para. (1) through (7). As appearing throughout these paragraphs, the word "contract" shall be construed to mean "agreement" and the word "contractor" shall be construed to mean Cooperative Extension Service, University of .

7. No member of or delegate to Congress shall be admitted to any share or part of this agreement, or to any benefit that may arise therefrom; but this provision shall not be construed to extend to this agreement if made with a corporation for its general benefit.

IN WITNESS WHEREOF, the parties whose signatures appear below must admit to having authority to enter into such agreements and agree that this agreement shall become effective on the date of the last affixed signature.

MARY NELL GREENWOOD
ADMINISTRATOR

Date

DIRECTOR, COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF

Date

AGREEMENT

THIS AGREEMENT, by and between UNIVERSITY OF a public corporation of the State of on behalf of the Cooperative Extension Service of the University of (hereafter "University Extension") and of (hereafter "Farm Participant").

WITNESSETH:

WHEREAS, University Extension has sought funds from the U.S. Department of Agriculture to study and

WHEREAS, Farm Participant is desirous of participating in this study of solar heating on his/their farm located at ; and

WHEREAS, it is necessary that University Extension enter into agreements with prospective participants in advance of the award of said grant by the U.S. Department of Agriculture;

NOW, THEREFORE, in consideration of the above and foregoing and the terms, conditions and mutual promises set forth hereafter, the parties mutually agree as follows:

1. That the Farm Participant will allow and cooperate in the construction of a Solar Heating Device or System (hereafter "Solar System") on Farm Participant's located on the above-referenced farm and shall secure and enter into any and all contracts necessary for such construction.

2. That the Farm Participant will construct and manage the Solar System in accordance with design specifications provided by University Extension.

3. That the Farm Participant will assist University Extension personnel in the collection of data regarding the Solar System as requested by University Extension personnel.

4. That Farm Participant will consult with University Extension personnel whenever necessary to maintain proper operation of the Solar System.

5. That Farm Participant will cooperate with and allow the preparation of publicity about the Solar System and the conducting of tours by various groups to study the Solar System operation. All public access to and/or tours of the Solar System shall be done in cooperation with the Farm Participant and shall be done at times and in a manner so as to minimize

the potential of disease transmission and disruption of Farm Participant's operations; provided, however, that University Extension shall assume no responsibility whatsoever for any damages arising from such a tour or tours.

6. That Farm Participant will allow University Extension to make whatever studies, tests and/or reports necessary to fulfill its obligations under the grant and Farm Participant will cooperate as necessary.

7. That Farm Participant shall keep accurate and complete records of all construction costs to serve as a basis for the cost-share allocation from University Extension.

8. That University Extension shall provide the following services to Farm Participants:

a. Provide Farm Participant with solar design criteria and specifications for the Solar System to be constructed by Farm Participant, provided, however, that Farm Participant shall have final approval of the design to be used;

b. Consult with Farm Participant during construction as necessary with regard to construction;

c. Arrange for the installation of necessary recording equipment for an evaluation of the Solar System;

d. Collect and evaluate data from the Solar System;

e. Arrange for and conduct tours or demonstrations of the Solar System in such a manner as to not interfere with good management practices of Farm Participant's Farm;

f. Prepare informational summaries and handouts describing the Solar System and its effectiveness;

g. Provide consultation as needed for day to day operations of the Solar System after completion and until termination of this agreement, provided, however, that University Extension shall not assume any responsibility for repairs required by the Solar System after its construction.

9. University Extension will pay one-half the cost of the Solar System to the Farm Participant; provided, however, that University Extension will only assist with construction of the Solar System and any costs relating to new buildings and/or

facilities are the sole responsibility of the Farm Participant. Said payment by University Extension shall be payable upon completion of operational testing on the Solar System and upon submission by Farm Participant of accurate and complete records of construction costs. This payment is the only financial payment assumed by University Extension.

10. This agreement shall become affective as of the award of funds to University Extension by the U.S. Department of Agriculture and shall terminate on   or after the Solar System has been in operation for two full years, whichever occurs later; PROVIDED, HOWEVER, THAT THIS AGREEMENT IS SPECIFICALLY CONTINGENT ON GRANT FUNDS AND SHOULD THERE BE NO AWARD OF FUNDS TO UNIVERSITY EXTENSION BY THE U.S. DEPARTMENT OF AGRICULTURE UNDER THE SOLAR SYSTEM STUDY GRANT, THIS AGREEMENT SHALL BE VOID AND IMMEDIATELY OF NO EFFECT.

11. Farm Participant shall not proceed with any actual construction and/or expenditure of funds until approved by personnel of University Extension.

12. Any and all ownership interests of University Extension in the Solar System as completed and/or materials used in the construction thereof shall be transferred to Farm Participant at such time as the cost-share payment provided for in paragraph 9 above is made.

13. Farm Participant and University Extension shall not be considered joint venturers and/or partners in the construction of the Solar System and Farm Participant shall assume responsibility for any and all claims or liabilities which result from actual construction of the Solar System.

14. This agreement may be cancelled by either party, without liability, by providing thirty (30) days advance written notice to the other party; provided, however, that Farm Participant may not cancel the agreement without the mutual agreement of University Extension after the cost-sharing payment has been made by University Extension.

15. Should Farm Participant terminate this agreement prior to the cost-sharing payment by University Extension, University Extension shall assume no responsibility for construction costs incurred prior to termination; for removal of the solar equipment installed; and/or for restoration of the premises to their former condition.

16. University Extension shall exercise due care in developing the design and specifications for this project and

shall secure peer review of the final design submitted to Farm Participant; provided, however, that University Extension makes or implies no guarantee of performance by the Solar System and NO WARRANTIES OF ANY SORT ARE MADE BY UNIVERSITY EXTENSION.

17. Farm Participant shall bear the risk of loss for destruction or damage to the Solar System during construction and upon its completion and shall be required to maintain adequate insurance to protect its interests therein.

18. This agreement sets forth the entire understanding of the parties and supersedes any and all prior agreements, arrangements and understandings relating to the subject matter hereof. This agreement shall be binding upon and inure to the benefit of the parties and their respective successors, legal representatives and assigns. The Article of Section headings, if any, of this agreement are for convenience of reference only and do not form a part hereof and do not in any way modify, interpret or construe the intentions of the parties. This agreement shall be executed in one or more counterparts and all such counterparts shall constitute one and the same instrument.

19. This agreement shall be deemed to have been entered into under the laws of the State of   and the rights and obligations of the parties hereunder shall be governed and determined according to the laws of said state.

20. No member, individually or collectively, or officer of the   University of   incurs or assumes any individual or personal liability by the execution of this contract or by reason of the default of the University in the performance of any of the terms hereof. All such liability of members or officers   of the University of   as such, is hereby released by the Farm Participant, as a condition of and in consideration of the execution of the contract.

IN WITNESS WHEREOF, this agreement has been executed by the parties as of the dates shown below the respective signature.

FARM PARTICIPANT	UNIVERSITY EXTENSION
Print Name	Print Name
Signature	Representative Cooperative Extension Service University of
Date	Date

APPENDIX B

State Final Reports

- Florida
- Illinois
- Kansas
- Maryland
- Michigan
- Missouri
- South Carolina
- Tennessee
- Virginia

245 On-Farm Demonstrations of Solar
Drying of Crops and Grains,

Final Report

Submitted By

Cooperative Extension Service
University of Florida

Agricultural Engineering Department
Gainesville, Florida 32611

December 30, 1982

TABLE OF CONTENTS

The remainder of this report consists of the following individual demonstration final reports:

ON-FARM DEMONSTRATIONS OF SOLAR DRYING OF CROPS AND GRAINS IN FLORIDA

INTRODUCTION:

The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) has initiated funding of five to ten pilot projects in on-farm demonstrations of solar drying of crops and grains in each of nine states.

Florida was selected for participation in this program, and awarded $105,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

OBJECTIVES:

1. Design, construct and evaluate full-scale prototype solar drying system on operating farms.

2. Demonstrate technical and economic feasibility of using solar energy technology to provide significant of heating requirements for on-the-farm crop and grain drying, as well as supplemental uses.

3. To test solar energy technology developed using research conditions under operating farm conditions.

4. To incorporate and utilize energy conservation techniques.

5. To mimimize interuption and interference in cooperators' normal operations.

6. To identify incentives and opportunities for widespread applications of solar energy technology - in other words extension packets on successful demonstrations.

APPROACH:

The solar systems were selected on a simplistic, pragmatic approach stressing:

1. Simple construction.

2. Low cost materials.

3. 20%-30% efficiencies.

4. 10°-30°F temperature rise.

5. 2-4 cfm/ft^2 air flow rate.

6. Use primarily as pre-heater to reduce fossil use of conventional equipment (no heat storage).

STATE COVERAGE AND CROP VARIETY:

The project consists of solar dryers located at ten separate locations with good coverage of the State, and good crop variety (two citrus, two potato, four corn, one peanut, and one small grain/grass seed). Table 1 lists the cooperators to be used in the demonstration, and Figure 1 indicates the location of the demonstrations.

COLLECTOR DESIGN VARIETY:

The project also involves good solar collection design variety:

2 - inflated plastic collectors with suspended screens

1 - roof mounted plastic collector

4 - roof retrofit bare-plate collectors

2 - roof mounted covered-plate collectors

1 - covered-plate collector incorporated in the construction of a new roof

1 - free-standing portable covered-plate collector.

CONSTRUCTION:

At the inception of this project, there were no full-scale solar drying systems installed in the State of Florida. After a considerable amount of effort, ten potential cooperators were identified and conceptual designs for ten projects were completed. The design work was slow due to the difficulty in hiring a project engineer. The diversity of the collector designs resulted in several individual designs rather than an adaptation of a common design. This resulted in more time required to prepare the ten project designed, but ultimately enhanced the project by generating more information. Another factor which delayed the project design schedule was the disperse locations of individual projects. All the projects required at least a half day for visits and three required two days for a visit. This was a problem in design preparation, but it too was an enhancement of the project. Once the designs were approved management of all phases of the construction began.

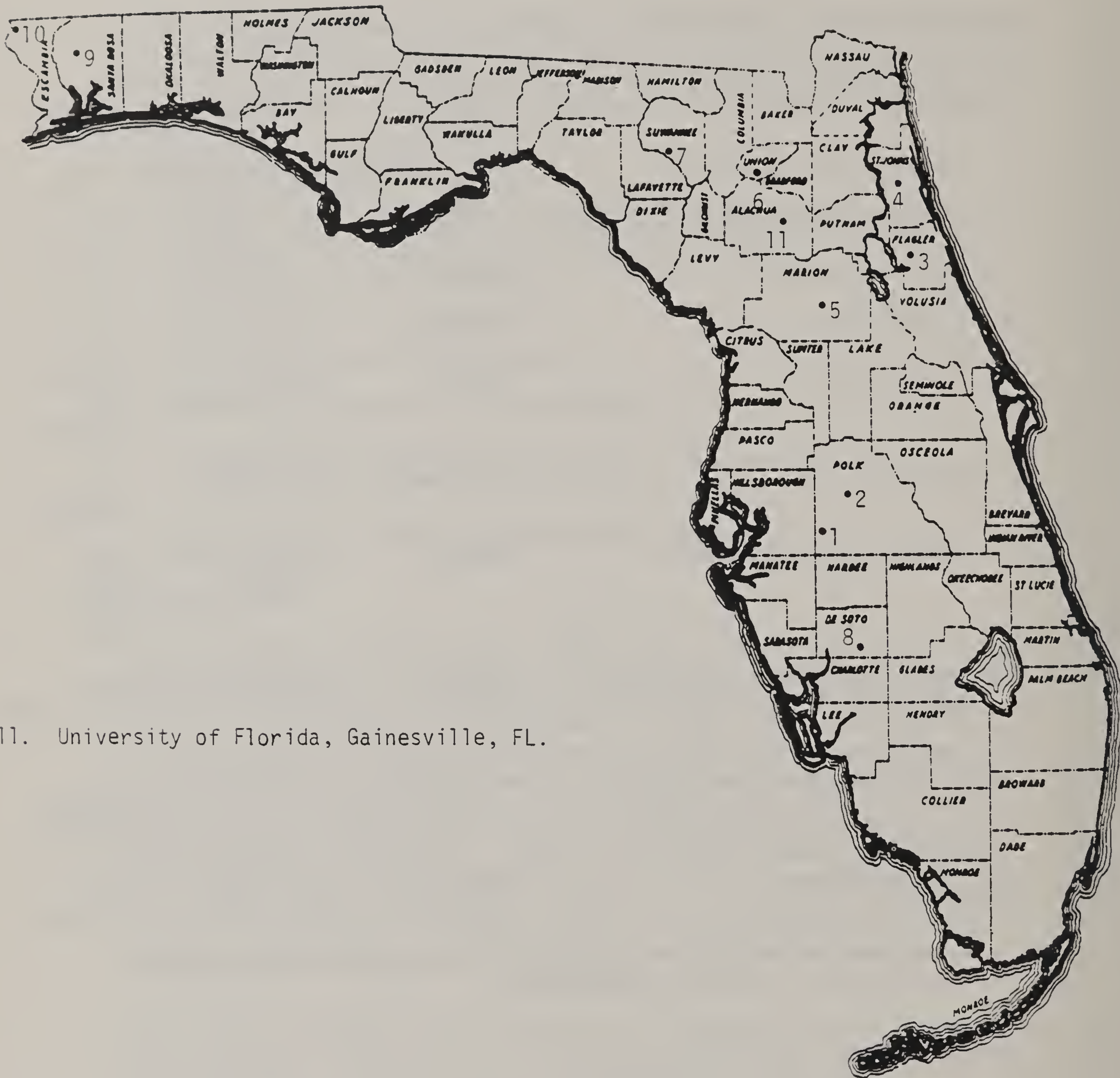
Our approach to project implementation and management was to purchase the solar construction materials and provide technical plans and assistance to cooperators. The cooperator was responsible for the construction of the solar collectors in accordance with the technical plans. At his option he could use local labor, available farm labor or contractors as he deemed necessary. This approach offered the advantage of greater return on the dollars invested. The approach also supported the objective of development of extension plans packets with which an average farmer could construct his own solar collector with locally available materials without having to go to more expensive contracted work. A disadvantage of our approach when compared to contracted construction work is the loss of a certain amount of control over the construction time schedules, and to a certain extent, quality control and system performance.

TABLE 1. AVAILABLE FACILITIES

Below is a list of cooperators to be used in the demonstrations.

Demonstration Cooperator	Florida Location	Building	Crop(s)
1. Lake Garfield Citrus Co-op	Lake Garfield	Packinghouse	Citrus
2. Winter Haven Citrus Growers Ass'n	Winter Haven	Packinghouse	Citrus
3. Johnston Brothers	Bunnell	Packinghouse	Potato
4. Byrnes Farms, Inc.	Hastings	Packinghouse	Potato
5. D.A. Lewis, Jr.	Ocala	Grain Bins & Drying Wagons	Peanuts Corn Sorghum
6. Ray Gay	Providence	Grain Bins	Corn Sorghum
7. Summer's Harvest Seed Co.	McAlpin	Drying Shed & Wagons	Oats Wheat Peas Rye
8. DeSoto County Land and Cattle Company	Arcadia	Equipment Shed	Corn Grass Seed
9. C & L Farm (John Creel and James Lee)	Allentown	Grain Bins	Corn Sorghum Soybeans
10. Gerald Boeckner	Walnut Hill	Grain Bins	Corn Soybeans

Locations of the above facilities are indicated by number on the map (Figure 1) on the following page.



11. University of Florida, Gainesville, FL.

Figure 1 - Location of Demonstrations

The approach to our management of this project required considerable administrative details. Coordinating material purchase and delivery for distant located projects at times caused construction delays. The farmers themselves had to work the solar collector construction into their management schedule and this also caused varying degrees of delay. Generally the farmers did not want to work on the construction after a particular crop season and did not want to begin construction until shortly before the next drying season. Several times other delays resulted when the construction work began to interfere with harvesting or other farm operations and the construction was again set aside. The great distances to some of the projects reduced some of the close supervision that would have been desired. The objective to minimize interuption to the normal farm operations and a desire to maintain good rapport with the cooperators resulted in very diplomatic application of pressure to speed up the completion of the construction.

The timing of the project funding and design approvals was out of mesh with the drying seasons of the crops of several of the projects. Because of the early harvest in Florida for most of the crop applications, the demonstrations were not operational for the first year's crops for most of the projects. As mentioned above, the farmers tended to lose interest in the project construction after the drying season until shortly before the next harvest and coordination of construction completion with drying seasons varied according to the management skills and motivation of the individual cooperator. Not all the demonstrations were completely operational for the drying of crops during the second and last season of this project.

The quality of the finished solar collector construction varied from demonstration to demonstration depending primarily on the construction expertise and management skills of the individual cooperator. Several were outstanding while others were not constructed as well as anticipated. However, this allowed us to evaluate opportunities to improve the designs, materials selected, etc.

The best construction was on the Summer's Harvest Seed Company and D. A. Lewis Jr. Farms. The poorest construction was on the C & L Farm collector. The others ranged between these two extremes depending, as mentioned, on the expertise of the cooperator or skill of the available farm labor, local labor, or contractors selected for the construction.

At present, all the projects have been constructed with the exception of the portable collector which was added to the Gerald Boeckner project. Mr. Boeckner completed the construction of the primary solar collector, but his farm management schedule has not allowed him an opportunity to complete the smaller collector. The materials for this collector are on hand and should not take a great deal of effort to complete. The plastic collector on the C & L Farm was damaged extensively during operational testing as a result of poor construction technique rather than design problems. Materials have been obtained to reconstruct the collector before the next corn-drying season in July of 1983.

Some construction design changes were necessary and additional design modifications for improvement have been identified, but for the most part the construction has verified the worth of the system designs and the major problems with project construction have resulted from construction techniques.

PERFORMANCE:

The performance level of all of the demonstrations in the State of Florida should be considered basically at the end of Phase I or at the conclusions of operational testing phase. Additional testing, including longer evaluation periods as well as in-season testing must be accomplished in order to fully evaluate the the efficiency and economic returns on the investments in these systems. The individual performance of each demonstration will be covered in the individual reports.

Overall the performance of several of the collectors would be classified as very successful. Two of the cooperators, Summer's Harvest Seed Company and D. A. Lewis Jr are very pleased with the performance of their collectors and feel that they have already received economic returns from utilization of their system. Two of the other cooperators, the Winter Haven Citrus Growers Assoc. and the Gerald Boeckner demonstrations involve bare-plate collectors which just did not produce the amount of energy that perhaps the cooperator had anticipated. However they were within the expected design performance as far as temperature rise goes for this type of collector for which the investment was low.

The performance of each individual project enclosed in the individual reports is based on limited data and additional testing will be required for a better performance evaluation.

INSTRUMENTATION:

In retrospect the planning of the instrumentation for this project was inadequate. Initially we planned to use two levels of instrumentation, 10 point thermocouple displays installed on each site in addition to mechanical hygrothermographs and mechanical pyronometers. The farmer and visitors could use the 10 temperatures at will. A recorder could be coupled to these for short duration records. The main purpose of the readout meters was to provide comprehensive information on the system for unscheduled visitors in addition to aiding the farmer in managing the drying system. The main data acquisition system was to be data loggers.

The 10 point thermocouple meters and mechanical pyronometers and hygrothermograph were purchased specifically for each project while the data loggers were to be drawn from University resources. The data loggers were to be moved from project site to project site and left unattended for short duration recording of data. However, only one data logger was available due to a lot of mechanical breakdown of existing equipment and this data logger was available only for the two citrus projects. A second data logger was purchased, a Campbell Scientific Unit, and upon receipt, this new instrument had a lot of maintenance problems and debugging before it could be used. In fact a couple of weeks' data on two projects was lost because of mechanical failure on the part of this instrument.

It now appears that, for the number of projects involved, an additional data logger would almost be necessary. The mechanical pyronometers, and possibly the mechanical hygrothermographs, could have been eliminated and the investment used to purchase this equipment could easily have been used to purchase an additional data logger.

Overall, the instrumentation portion of this project was somewhat of a hindrance. The initial planning did not anticipate some of the problems encountered and the mechanical difficulties with the equipment used also was a problem.

UTILIZATION:

Since the project is basically at the completion of Phase I, the majority of the information related to the project has been in the form of what was to be done and the expected performance. Presentations have been presented at Extension training meetings, technical meetings, and several articles have appeared in newspapers, popular magazines, and on television.

A survey of interest concerning individual project reports was sent out in the early part of the project. The response at that time from the counties was great. The individual project reports attached will be disseminated to all the counties in the State. It is hoped that the limited budget we are operating on here at the State level that in cooperation with the counties involved this education effort can be continued during the next year as well as monitoring and improvement of the systems as necessary. Excellent project signs have been prepared and erected on the projects to attract local interest and additional educational-type programs both on-site visits and development of more detailed Extension publications are planned.

PERSONNEL:

The major contributers toward the project objectives were:

M.T. Talbot, P.E., BS, ME Agricultural Engineering
Project Manager - Principle Investigator
Assistant Professor - Extension Agricultural Engineering
University of Florida
Agricultual Engineering Department
Gainesville, Florida 32611

W.M. Miller, P.E., BS, MS, Ph.D., Agricultural Engineering
Project Engineer - Citrus Demonstrations
Associate Professor - Agricultural Engineering
University of Florida, IFAS
Lake Alfred Agricultural Research
and Education Centers
Lake Alfred, Florida 33050

M.K. Elfino, P.E., BS, ME, Agricultural Engineering
Project Engineer - All demonstrations excluding citrus - Engineer I
University of Florida, IFAS
Agricultural Engineering Department
Gainesville, Florida 32611

Several other university and county faculty contributed in various degrees.

COMMENTARY:

Although as mentioned, the project is basically at the completion of Phase I a great deal of work has been accomplished during this project. Starting from scratch and obtaining 10 cooperators with suitable applications and managing these 10 separate projects which were located so far apart is an accomplishment in itself. The project management method which was employed resulted in a greater burden on the project personnel than might otherwise have been necessary if a simpler approach had been taken. Fewer projects would have been easier to manage and more could have been perhaps accomplished with fewer projects.

The reduced interest in the energy crisis during the last year has taken away some of the glitter of this type of work. As mentioned above, we were faced with material delays, construction delays on the part of the cooperators, equipment failure as far as instrumentation goes, flooding, solar collector component failure, the death of one of the cooperators, and the near financial failure of another cooperator. The instrumentation planning also caused major problems as did the delay in selection of a suitable project engineer.

Much has been gained from these projects and it is hoped that this benefit can be continued through additional efforts with the projects. It is unfortunate that this project final report is due a year earlier and that at most only one drying season data has been included for each project. Fortunately, with the extension of second year funding and the release of a portion of the budgeted third year funding, positive plans to continue the system improvement, monitoring, and demonstration have been made. In addition, funding from the State Extension office allowed the retention of the project engineer through June 1983. He will concentrate on maximizing the educational-type programs, including on-site programs and improved extension-type literature.

For more information contact:

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UNIVERSITY OF FLORIDA

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AGRICULTURAL ENGINEERING DEPARTMENT
FRAZIER ROGERS HALL
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December 30, 1982

245 Lake Garfield Citrus Co-op Demonstration
On-Farm Solar Demonstration of Crops and Grains//

M. T. Talbot, P.E., Project Leader; W. M. Miller, P.E., Project Engineer

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: Lake Garfield Citrus Co-op is located in Lake Garfield, Florida (approximate latitude 28°N.)

DESCRIPTION OF FARM: This packinghouse handles fresh citrus during a season that extends from September through May. Packing is usually accomplished in one shift with total operating time of 1200 to 1400 hr/year. Volume of fruit packed from the 1978-79 and 1979-80 seasons averaged:

Grapefruit	Oranges	Speciality varieties
114,304 cartons	351,828 cartons	32,873 cartons

A Florida carton is 4/5 bu and holds approximately 19.25 kg of fruit.

This packinghouse converted to water wax after the 1979-80 season. The present drying operation entails: mechanical dewatering, fungicide application, water wax application plus surface drying. The Lake Garfield packinghouse was one of the first Florida operations to install dryers

with air recycling. Each drying unit module has both humidity and temperature control. A second return fan is configured to regulate percent air recycled. Solar heated air will be used in the first dryer to provide baseload heating for that unit. Supplemental heat will be available via existing air-steam heat exchanger.

Based on unpublished data (Bowman, E.K., USDA-SEA, Gainesville, FL), drying costs are approximately $0.04 per carton. Using the above mentioned production figures, drying costs for the Lake Garfield installation would be $26,600 per year with approximately $17,300 for direct energy costs.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar hot-air system to provide baseload heating for surface drying fruits and vegetables, specifically Florida citrus.

2. To evaluate a conventional solar heated air configuration with regard to collector efficiency and percent drying load available from solar.

3. To evaluate solar fabrication materials for a moderate industrial environment in a high solar intensity subtropical climate.

SOLAR SYSTEM DESIGN: The Lake Garfield Citrus Co-op has a free standing pole shelter, approximately 1550 ft^2, adjacent to the packingline dryers. This shelter serves to protect the fruit dumping, trash elimination and washing areas which are located outside the main packinghouse. The roof on this shelter was utilized to construct a solar hot-air collector. Air channels were created with nominal 2 in. x 6 in. spacers (2 ft on center) and a UV-treated fiberglass cover installed. Bottom polyisocyanurate sheet insulation was added to reduce conduction and convective heat losses. An in-line duct blower, approximately 5000 cfm free air capacity, and interconnecting ductwork were installed between the solar roof collector and the first packing-line dryer. Supplemental heat for the first drying module is available from an existing steam radiator. Controls for air recycling on the fruit dryer remained intact. Figures 1 and 2 show construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was $9,600 for an average cost of $6.19/$ft^2$ of collector surface.

PERFORMANCE: The solar drying system at the Lake Garfield Citrus Co-op is complete and in operation. The system has been used in the surface drying of citrus during the last two seasons and has functioned well. Last year the citrus packing season was drastically reduced by severe freezing. Mr. James Ellis, Co-op General Manager, is pleased with the system. The performance data collected indicates the performance conforms to design performance criteria.

During testing in April and November 1982, the average solar radiation at the packinghouse was 1765 BTU/ft^2 based on an 8 hour day. The total radiation for the 1550 ft^2 collector was 2.736×10^6 BTU/day. The air flow through the system was 4600 cfm. The average temperature rise was 30°F. The average energy gained was 1.192×10^6 BTU/day, resulting in an efficiency of 45%. The average relative humidity during the test period was 60%. The equivalent heating provided by L.P. gas would require 13.25 gallons and based on a cost of $1.00/gal, the amount of savings was $13.25/day. The packing season for citrus is 180 days/year. A simple cost analysis indicates a payback period of 4 years.

Figures 3, 4 and 5 show typical performance data. Additional collection data is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: Mr. Ellis hired a local carpenter to construct the solar collector while a sheet metal contractor installed the fan and duct work. The sheet metal work was superior to the carpentry work. This was the carpenter's first experience with solar collection and he expressed considerable interest.

The construction was of adequate quality but could have been improved. Exterior pressure-treated lumber should be used even though this lumber is protected from the weather. The 2 x 6's tie-in procedure to the existing roof structure must be improved since the "toe-nailing" did not provide enough stability and resulted in a poor support for the transparent cover. Also the 2 x 6 end to end connections should be reinforced with wood plates or gusset plates. The transparent cover should be lapped as in roofing to prevent leaking, but for this construction, overlapping was incorrect. Molding is needed to hold down the sheet insulation. Another problem resulted from the expansion and buckling of the aluminum batten. Allowance for thermal expansion of the aluminum batten must be made at the end of each piece and at screw holes. Some cheaper caulking was substituted and tended to chalk creating white powder in the air channels. Also, particulate matter from the boiler exhaust at Lake Garfield was noticeable as it accumulated on the fiberglass cover. Despite these numerous minor construction details, the collector provides an excellent temperature rise. The maximum temperatures in the collector did not occur at stagnation but were caused by an open steam valve to radiator coil of the existing drying system.

Mr. Ellis is pleased with the system and the demonstration is a good example of how solar collection systems can be retrofitted to existing structures. The use of the solar system to dry citrus is a good application since the citrus packing season last several months, requires temperatures in the neighborhood of 140°F and normally entails only daytime operations. No major design changes are planned but, further data collection and analysis will be studied for possible system operation and design improvements.

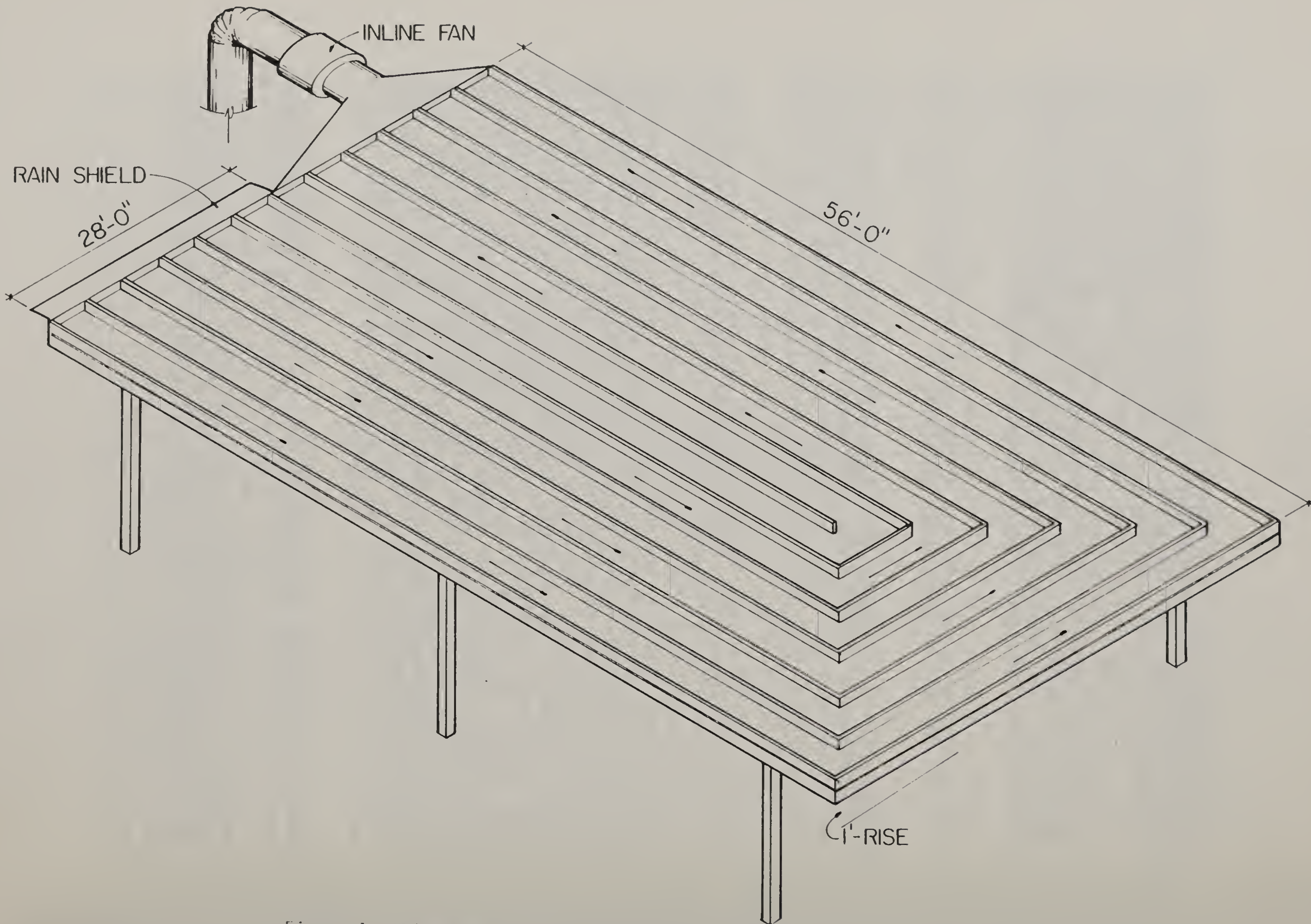

Figure 1. Diagram of air flow through system.

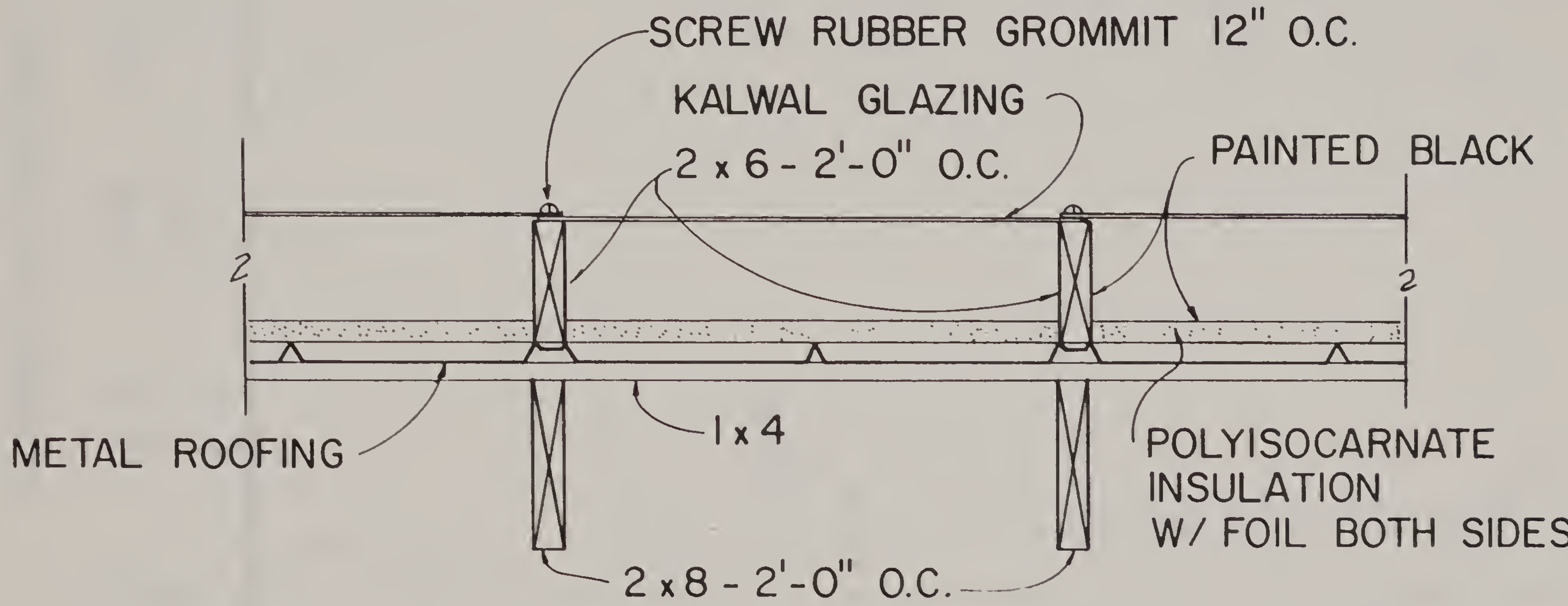

Figure 2. Diagram of cross-sectional construction detail.

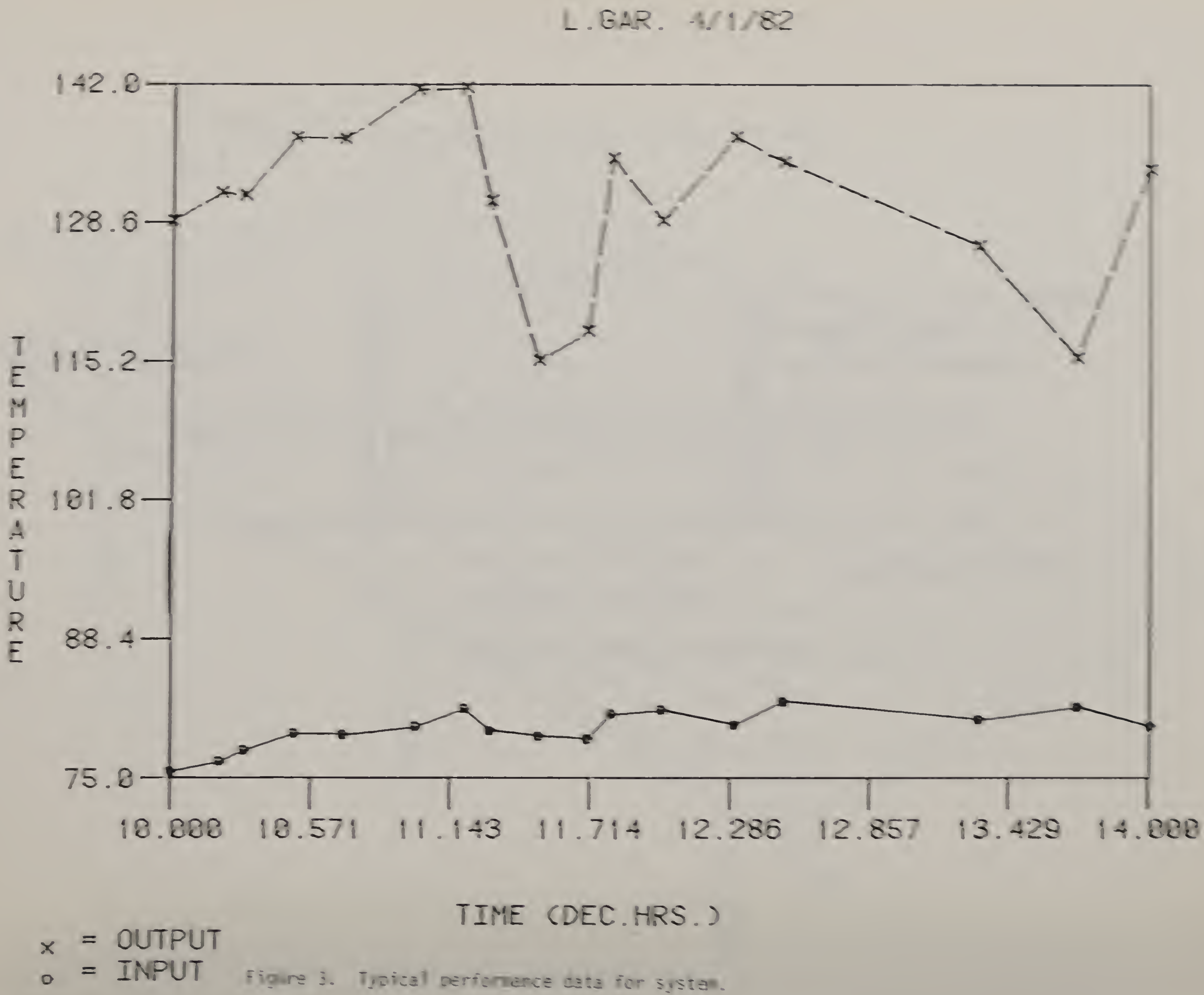

Figure 3. Typical performance data for system.

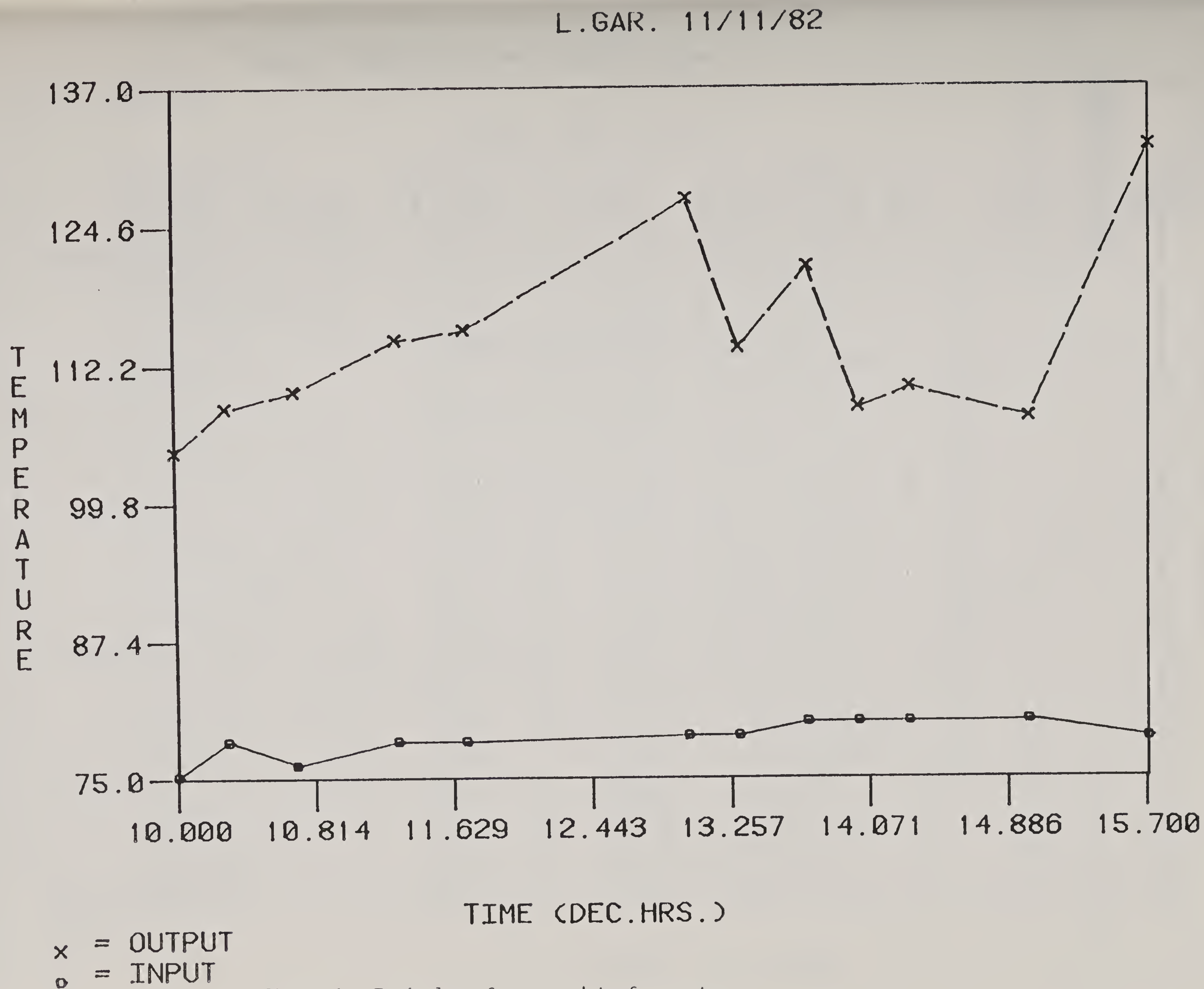

Figure 4. Typical performance data for system.

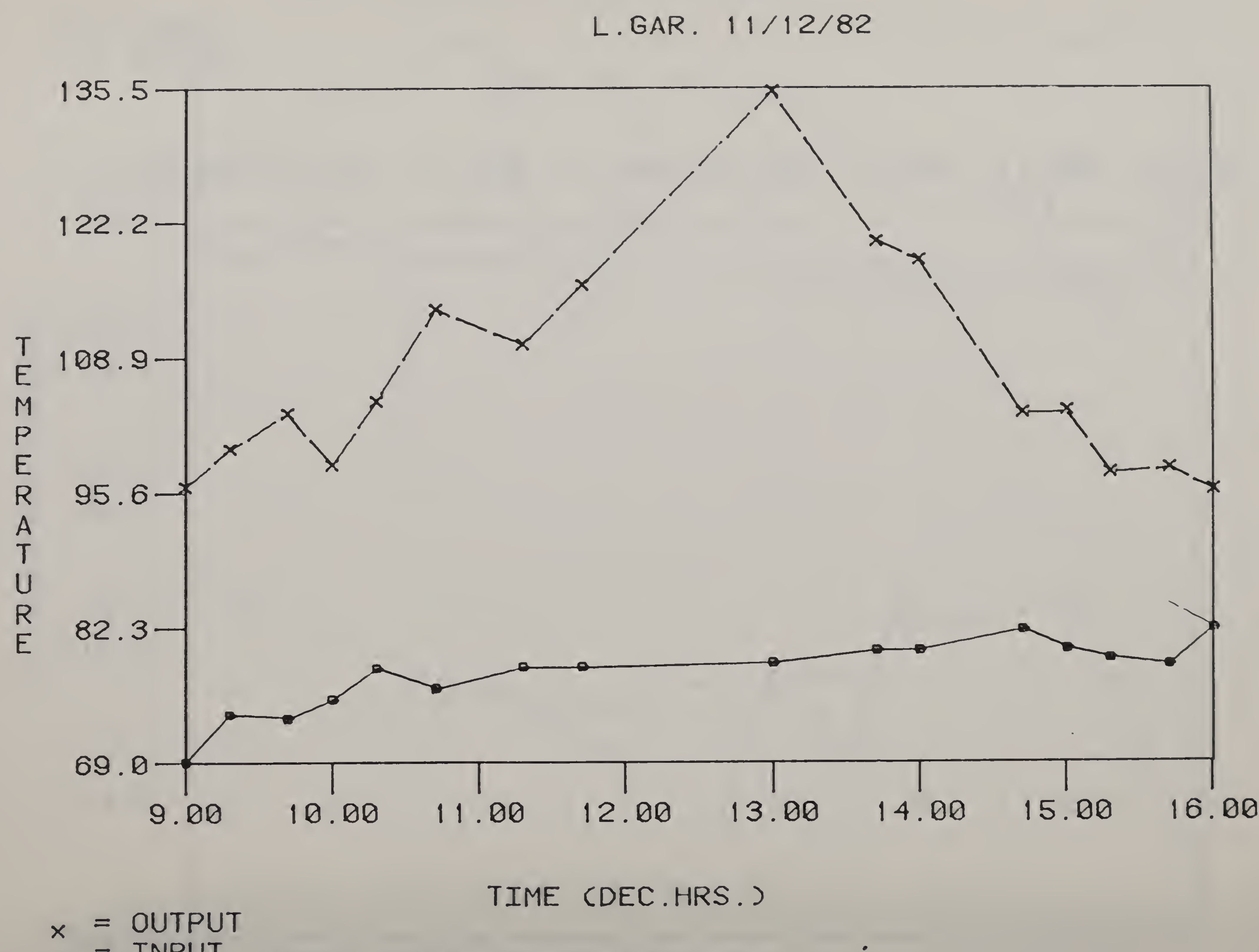

Figure 5. Typical performance data for system.

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December 30, 1982

Winter Haven Citrus Growers Association Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, P.E., Project Leader; W. M. Miller, P.E., Project Engineer

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: Winter Haven Citrus Growers Association is located in Winter Haven, Florida (approximate latitude 28°N.)

DESCRIPTION OF FARM: This packinghouse handles fresh citrus during a season that extends from September through May. Packing is usually accomplished in one shift with total operating time of 1200 to 1400 hr/year. Volume of fruit packed from the 1978-79 and 1979-80 seasons averaged:

Grapefruit	Oranges	Speciality varieties
248,874 cartons	448,290 cartons	269,898 cartons

A Florida carton is 4/5 bu and holds approximately 19.25 kg of fruit.

All of the packaged fruit requires surface drying which is an integral unit operation in the packingline. This packinghouse has just converted to a water-based waxing process which requires: mechanical dewatering with brushes and sponge rollers, wax application with spray nozzles and drying to vaporize water and allow the wax to set. Typically, this drying requires 1.75 to 3.00 min. at temperatures from 120°F (49°C) to 140°F

(60°C). The fruit is conveyed through a tunnel dryer on a roller conveyor and is turned periodically to expose contact areas.

Based on unpublished data (Bowman, E.K., USDA-SEA, ,Gainesville, FL), drying costs are approximately $0.04 per carton. Using the above mentioned production figures, drying costs for the Winter Haven installation would be $51,400 per year with approximately $33,400 for direct energy costs.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar retrofit for dryer perheat in surface drying fresh fruits and vegetables, specifically citrus.

2. To determine efficiency of collecting solar energy from loft areas in a packinghouse and establishing the percent of drying energy available from this source.

3. To assess low-cost control methodology for such installations.

SOLAR SYSTEM DESIGN: The Winter Haven CGA packinghouse is oriented N-S with loft areas (each with approximately 3,600 ft^2 solar exposure area) on both the east and west sides of the building. The center area on the second floor is used for carton storage and also serves as the accumulation area for palletizing packed cartons. To reduce the heat load for workers in the carton holding area, the side loft areas have been isolated from the worker area. To implement solar energy collection, the north ends of both side lofts were enclosed and air ducts installed to connect this solar heated attic area with the final fruit drying units. Separate ducts for the east and west areas were combined before the fruit dryer. By means of a manually controlled damper, air can be drawn from either east or west sections or a mixed proportion from both areas. Two blowers, approximately 8,000 cfm total free air capability, serve both for air flow through the solar collector and to provide forced air over a rolled-bed dryer to surface dry citrus fruit. Figure 1 shows construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was $3,200 for an average cost of $0.89 /$ft^2$ of collector surface.

PERFORMANCE: The solar drying system at the Winter Haven CGA packinghouse is complete and in operation. The system has been used in the surface drying of citrus during the last two seasons and has functioned well. Last year the citrus packing season was drastically reduced by severe freezing. Mr. E. A. Beeland, Executive Vice-President, is pleased with the project. Although this retrofit bare-plate collector does not produce a large temperature increase, energy conservation measured installed in conjunction with the solar system, but not part of the project, have further improved energy utilization during the citrus washing, waxing, and drying operations. The performance data collected indicates the performance conforms to design performance criteria.

During testing in May and October 1982, the average solar radiation at the packinghouse was 1765 BTU/ft^2 based on an 8 hour day. The total radiation for the 3600 ft^2 collector surface was 6.354 x 10^6 BTU/day. The air flow rate through the system was 5000 cfm. The average temperature rise (both east and west lofts) was 8°F. The average energy gained by the heated air was 345,600 BTU/day resulting in an efficiency of 5.4%. The average relative humidity during the test period was 60%. The equivalent heating provided by L.P. gas would require 3.5 gallons and based on a cost of $1.00/gal,, the amount of savings was $3.50/day. For a packing season of 180 days/year, a simple cost analysis indicates a payback period of 5 years.

Figures 2 and 3 show typical performance data. Additional collection data is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: Mr. Beeland used packinghouse labor to complete carpentry work while a sheet metal contractor installed the duct work and damper. The construction was of high quality.

After initial testing, the design was studied in an effort to increase the temperature rise of the air passing through the collector. The first approach was to reduce the duct (loft area) cross-sectional area to reduce poor air flow. It appeared that plastic sheets could be attached to existing roof truss members to satisfactorily reduce the cross-sectional area. However, a sprinkler system for fire protection located at the peak of the loft area would have been blocked if not relocated. Relocation of the sprinkler system was not deemed practical. Smaller cross-sectional attic space for bare-plate collectors is desirable.

A second approach to increasing the temperature rise was to paint the exterior roof black. Only the west side was painted black. Comparing the east and west side indicates a marked difference, with the temperature rise of the west side doubled that of the east side. Painting the east side is under consideration. The enclosed attic could be better sealed to reduce infiltration, which should increase the temperature rise.

Mr. Beeland is pleased with his system and the demonstration is a good example of how solar collection systems can be retrofitted to form bare-plate collectors. Although the energy produced is low compared to other systems the investment, labor required, and maintenance are low and make this a good system for many applications. No major design changes are planned but, further data collection and analysis will be studied for possible system operation and design improvements.

For more information contact:

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University of Florida
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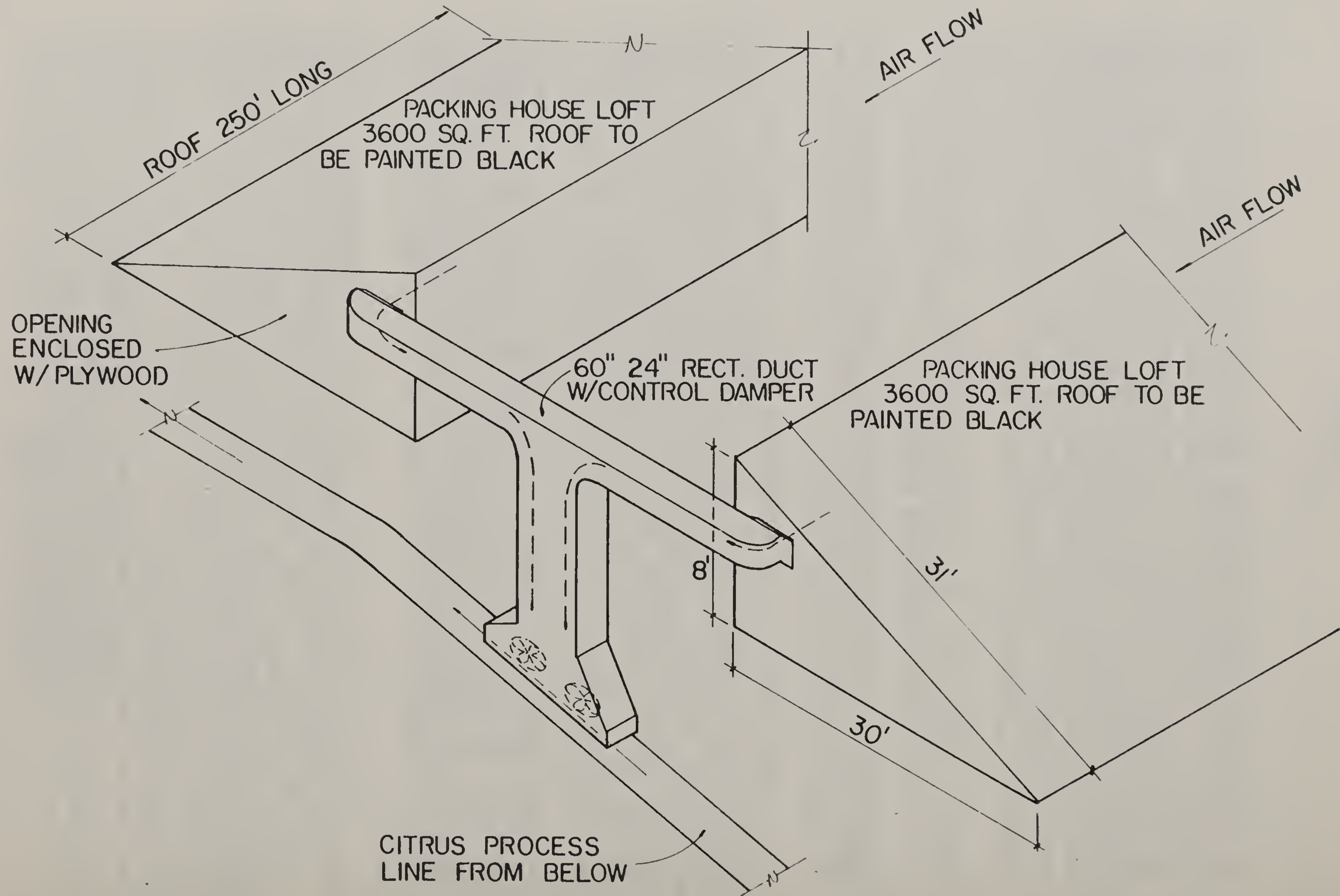

Figure 1. Diagram of air flow through system.

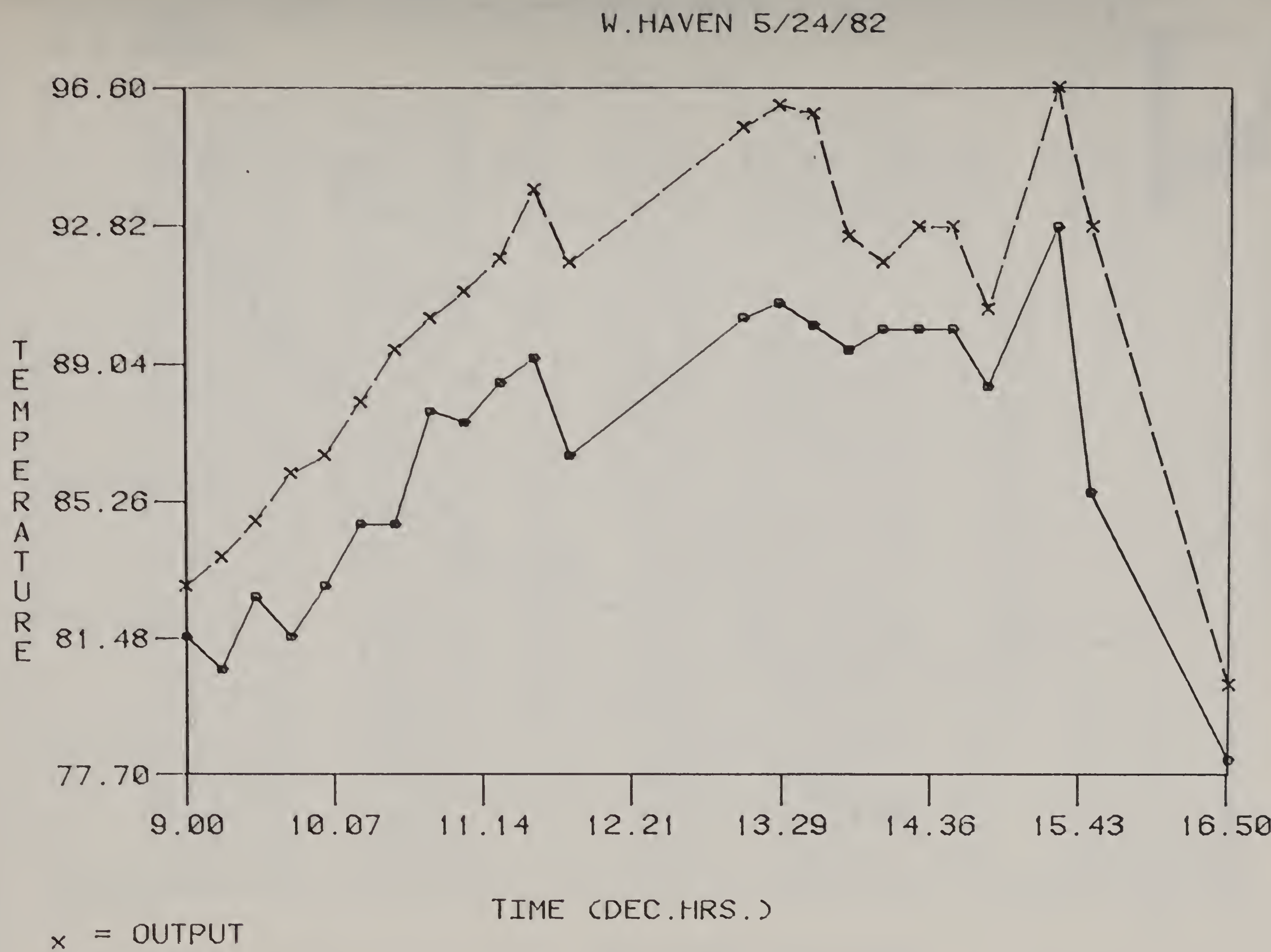

Figure 2. Typical performance data for system.

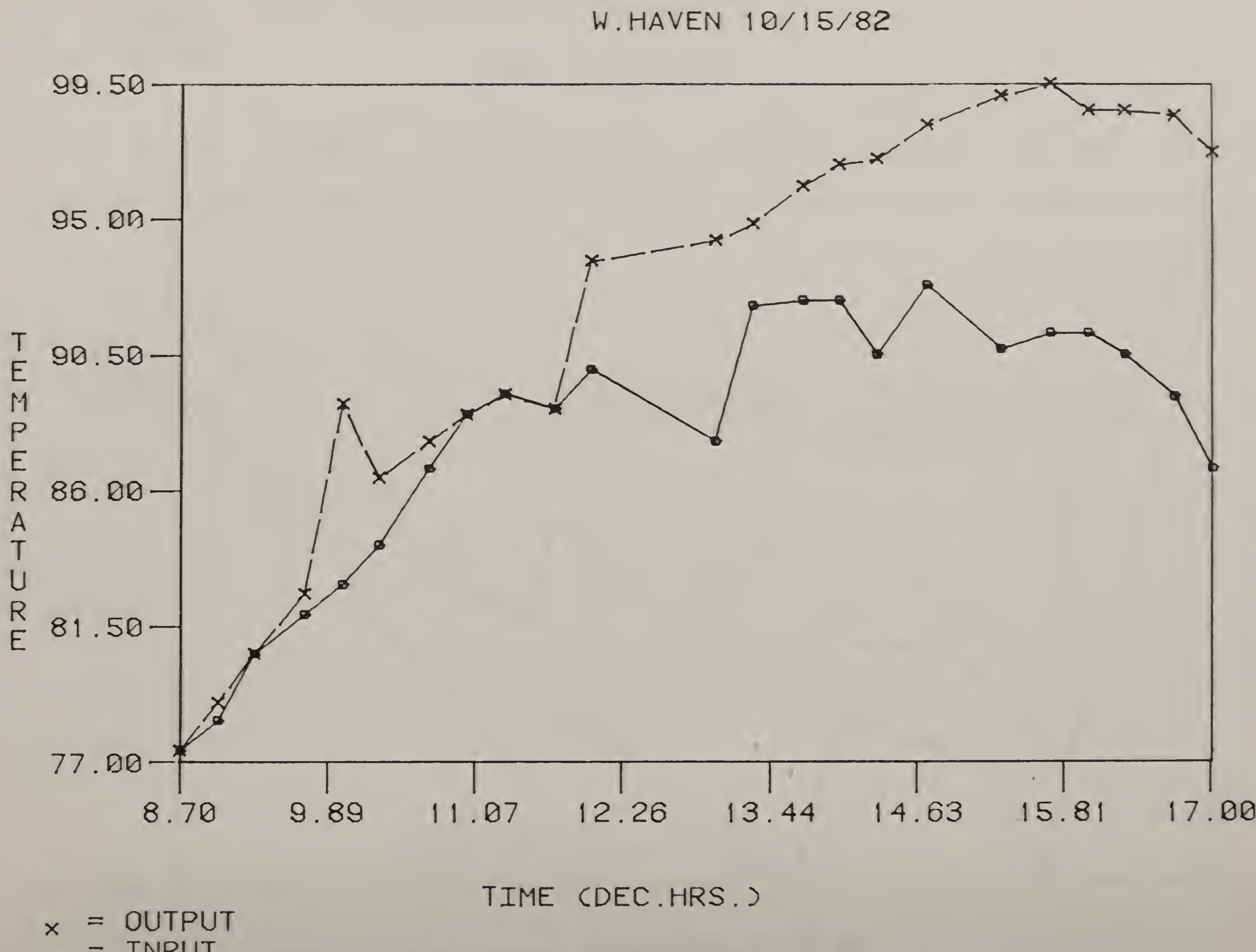

Figure 3. Typical performance data for system.

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December 30, 1982

Johnston Brother's Farm Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, P.E., Project Leader; M. K. Elfino, P.E., Project Engineer

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: The Johnston Brother's Farm is located 8 miles west of Bunnell, FL, on State Road 100 (approximate latitude 30°N).

DESCRIPTION OF FARM: The Johnston brothers farm 225 acres of cabbage (harvested December to mid-April), 500 acres of potatoes (harvested mid-April to June), followed by 80 acres of field corn (harvested August to September), and 150 acres of soybeans (harvested September to October). The cabbage is packed and sold for the fresh vegetable market. The corn and soybeans serve as cover crops and are custom harvested for direct sale with no storage facilities available.

The potato packinghouse is a modern facility housed in a 60 by 120 foot slant-side metal building. There is no inner covering under the clear-span roof; frame members (purlins and trusses) are fully exposed. The potatoes are trucked from the field and conveyed into a washing flume, then spray washed and passed through a modern machinery line, permanently installed in the packinghouse. The surface moisture is removed, after washing, by brushes, absorbent rollers, and dryer fans. The dryer fans (four 24 in., 1/4 HP, 4500 cfm) blow ambient air over the potatoes as

they are carried on a roller conveyor through the dryer before the grading operations. The potatoes are bagged in paper bags and loaded for shipment, primarily for table use. Production each year may be as high as 10 million pounds with a gross price of $500,000 to $1,000,000.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar hot-air system to provide baseload heating for surface drying fruits and vegetables, specifically Florida potatoes.

2. To evaluate a conventional solar heated air configuration with regard to collector efficiency and increased drying ability compared to ambient air drying.

3. To provide better surface drying, resulting in less unusable product at the destination point.

4. To secondarily reduce the heat load in the building for worker comfort, to prevent short circuiting of moist air by the dryer fans, and provide a source of winter heat when required.

SOLAR SYSTEM DESIGN: The potato packinghouse is oriented N-S with a solar exposed roof area of approximately 6,700 ft^2. A bare-plate solar collector was constructed by adding insulation board beneath the purlins to form 14 N-S air channels. An E-W collection duct (plenum) traverses the 14 channels and is connected to two of the existing four dryer fans (near the N-W corner of the packinghouse) with flexible duct. The two fans (providing 9,000 cfm at zero static pressure) draw air entering the air channels at the south of the purlins under the roof, where it is heated by 5,040 ft^2 of collector area, then passes the warm air over the potatoes on the roller conveyor. Figures 1 and 2 show construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was $3,730 for an average cost of $0.75/ft^2$ of collector surface.

PERFORMANCE: The solar drying system on the Johnston Brother's farm is complete and operational. The system was not in operation during the last potato season and has not been used to surface dry potatoes. Albert and John Johnston are pleased with the packinghouse insulation that the collector provides and look forward to using the solar system to surface dry potatoes next season. The insulation effect on the collector significantly reduced the indoor temperature of the packinghouse. Only limited performance data has been collected at present but performance appears to conform to design performance criteria.

During testing in October 1982, the average solar radiation at the farm location was 1200 BTU/ft^2 based on an 8 hour day. The total radiation

available for the 5,040 ft^2 collector was 6.048×10^6 BTU/day. The air flow through the system was 5,000 cfm. The average temperature rise was 12°F. The average relative humidity during the test period was 90%. The average energy gained by the heated air was 0.520×10^6 BTU/day, resulting in an efficiency of 8.6%. The equivalent heating provided by L.P. gas would require 5.8 gallons and based on a cost of $1.00 per gallon, the amount of savings was $5.80/day. The potato packing season is estimated to be 90 days. A simple cost analysis indicates a payback period of 7 years.

Figures 3, 4 and 5 show typical performance data. Data was collected while fans operated 24 hours per day. Additional data collection is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: Initially, the material selected to enclose the purlin space and form the heat collection air channels, was a 1/4 inch thermoply material. The purlins were not on exact 4 feet centers which required design of a fabricated sheet metal clip to install the thermoply. The materials were purchased and partially installed, however, the appearance of this system was not to the Johnston Brothers' liking. They were also concerned about possible future sagging. They attempted to use 1/2 inch styrofoam sheets which was not strong enough for this application. Finally they selected 3/4 inch insulation board which was installed across the width of the building. This material was more economical to install as well as easier to install than the material initially selected. The Johnstons used available farm labor to install the paneling (insulation board) material. University of Florida personnel installed the fiberglass duct-board duct which traversed the 14 channels as well as the three flexible drop ducts and the fan shroud.

The construction was of high quality. The major problem resulted in inadequate sealing between adjacent 4 x 8 foot insulation sheets. These joints were taped but the duct tape used tended to peel off. Retaping and stapling the tape should alleviate this problem.

The initial design called for use only two of the four existing drying fans to pull air through the collector was based on available manufactures performance literature. However, preliminary data indicates the air capacity for the two fans used was about half of that anticipated. Therefore, materials have been purchased to enclose all four fans with a shroud before the next drying season. This will increase the velocity through the 14 collection channels as well as eliminate the mixing of heated air from two collector fans with the ambient air from the other two fans.

The Johnston Brothers are pleased with their system and anticipate additional benefits when it is used during the next drying season. The demonstration is a good example of how bare-plate solar collection systems can be installed through roof retrofit of metal buildings. The only major design changes, other than the four fan shroud, being considered is to paint the exterior building roof surface flat black to increase the solar energy collection. However, further data collection and analysis will be studied for possible system operation ad design improvements.

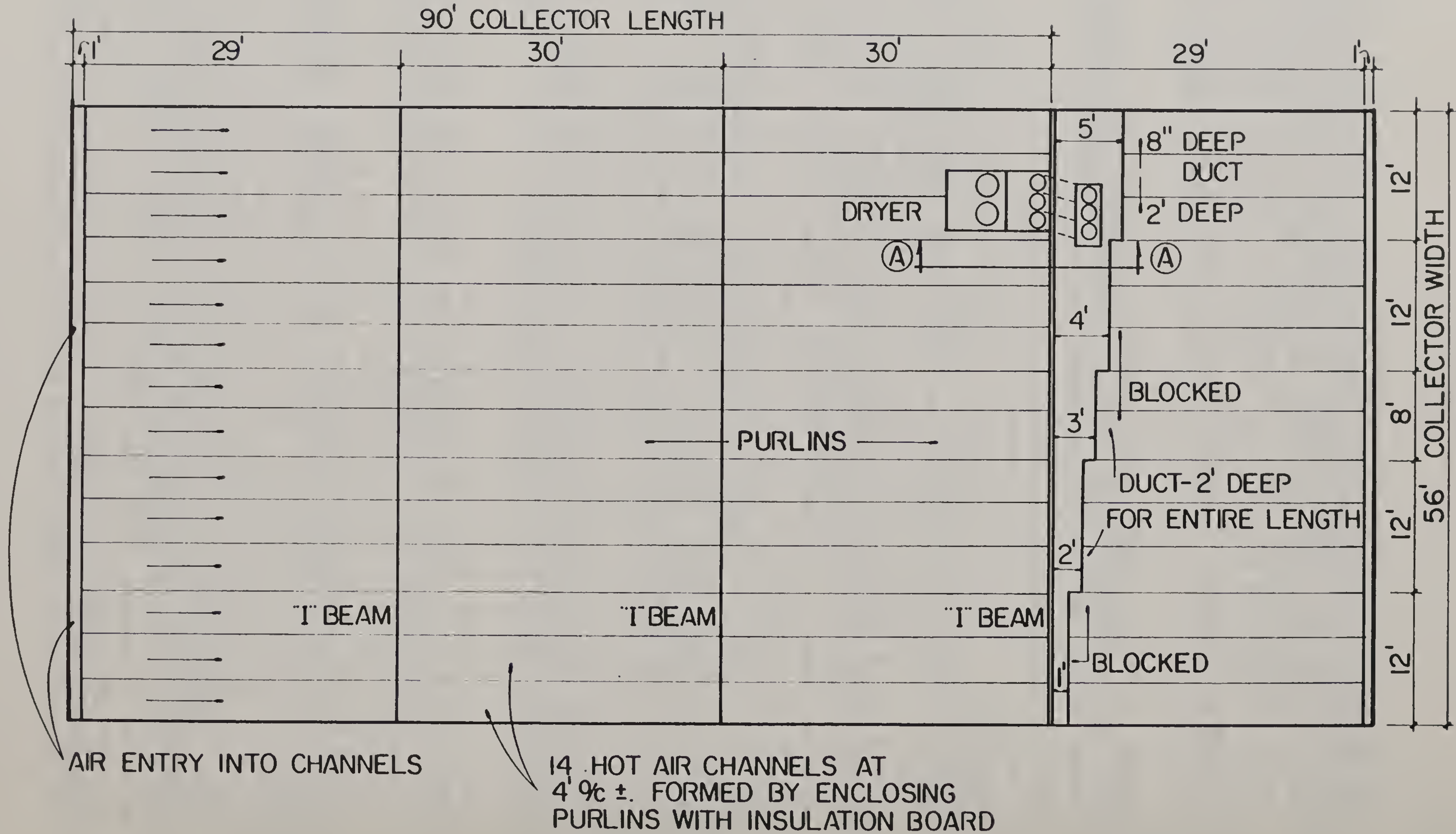

Figure 1. Diagram of plan construction detail.

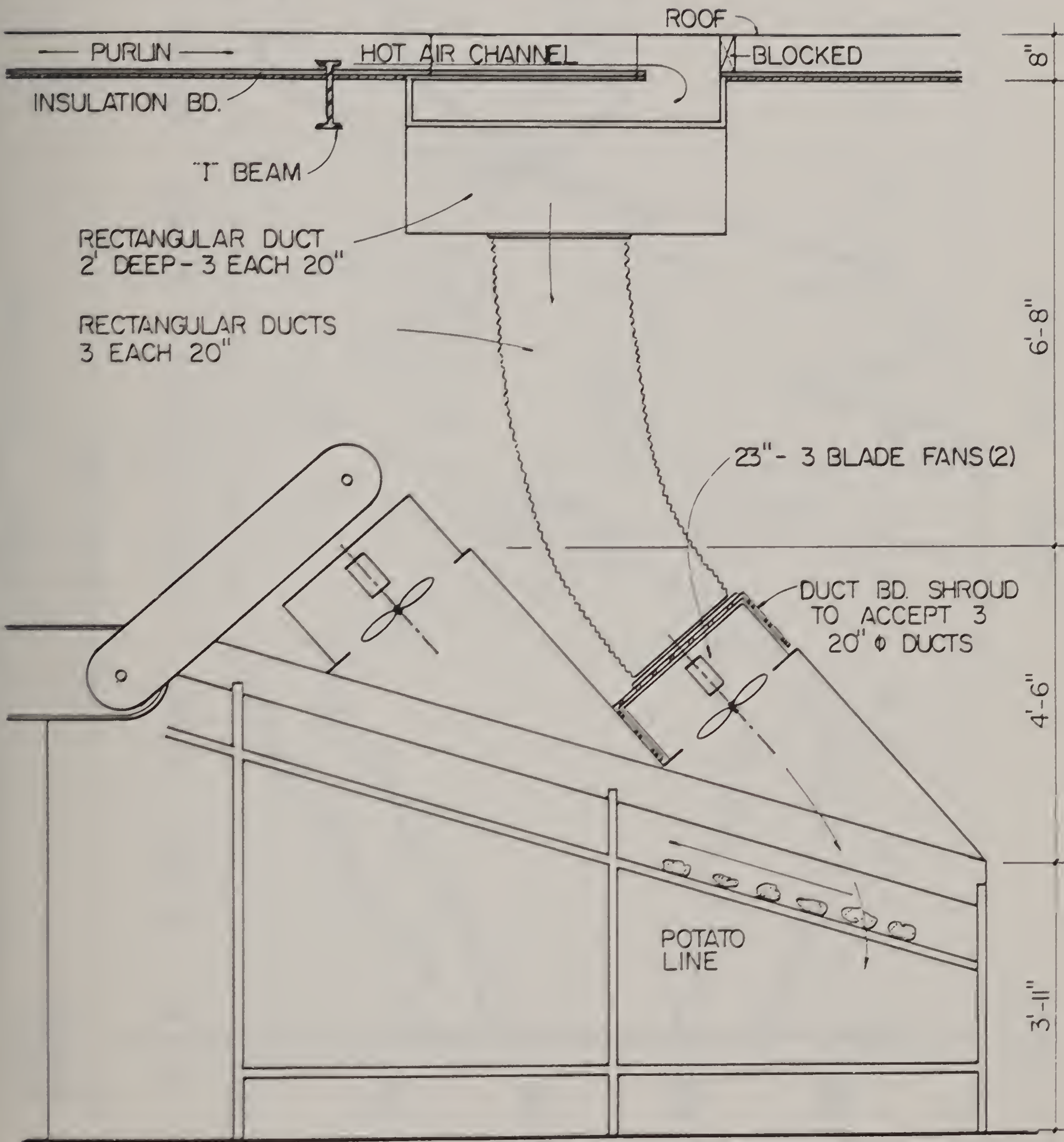

Figure 2. Diagram of cross-sectional construction detail.

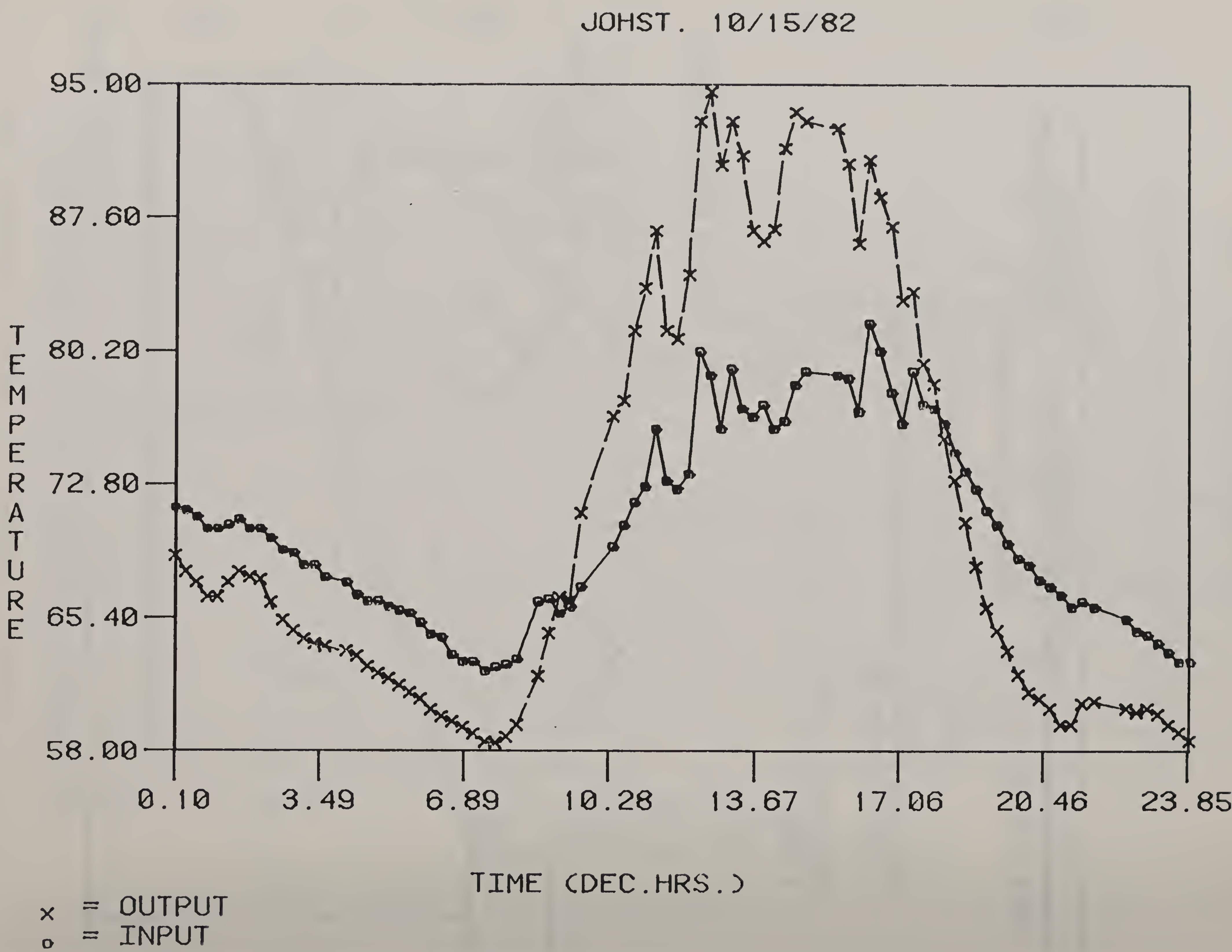

Figure 3. Typical performance data for system.

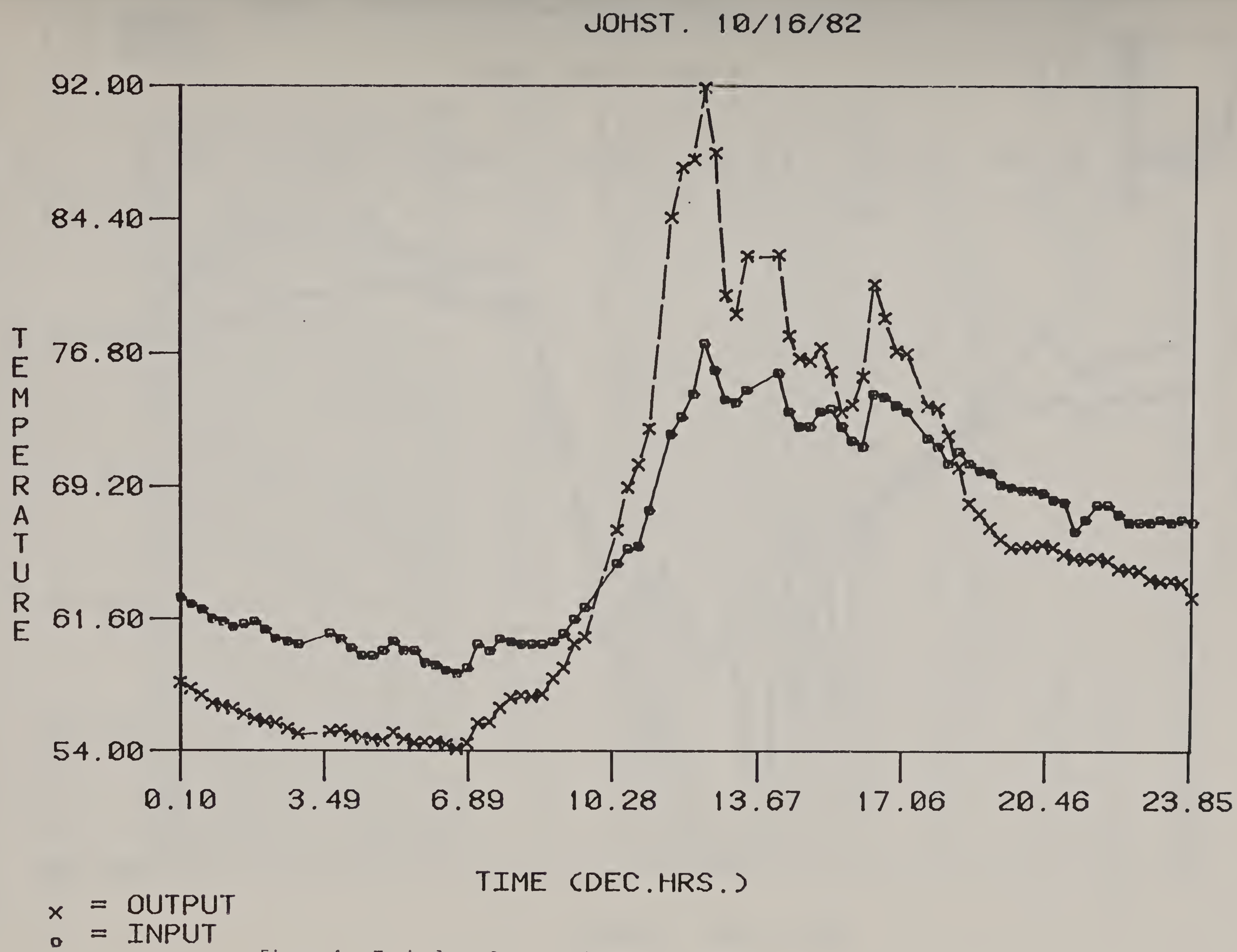

Figure 4. Typical performance data for system.

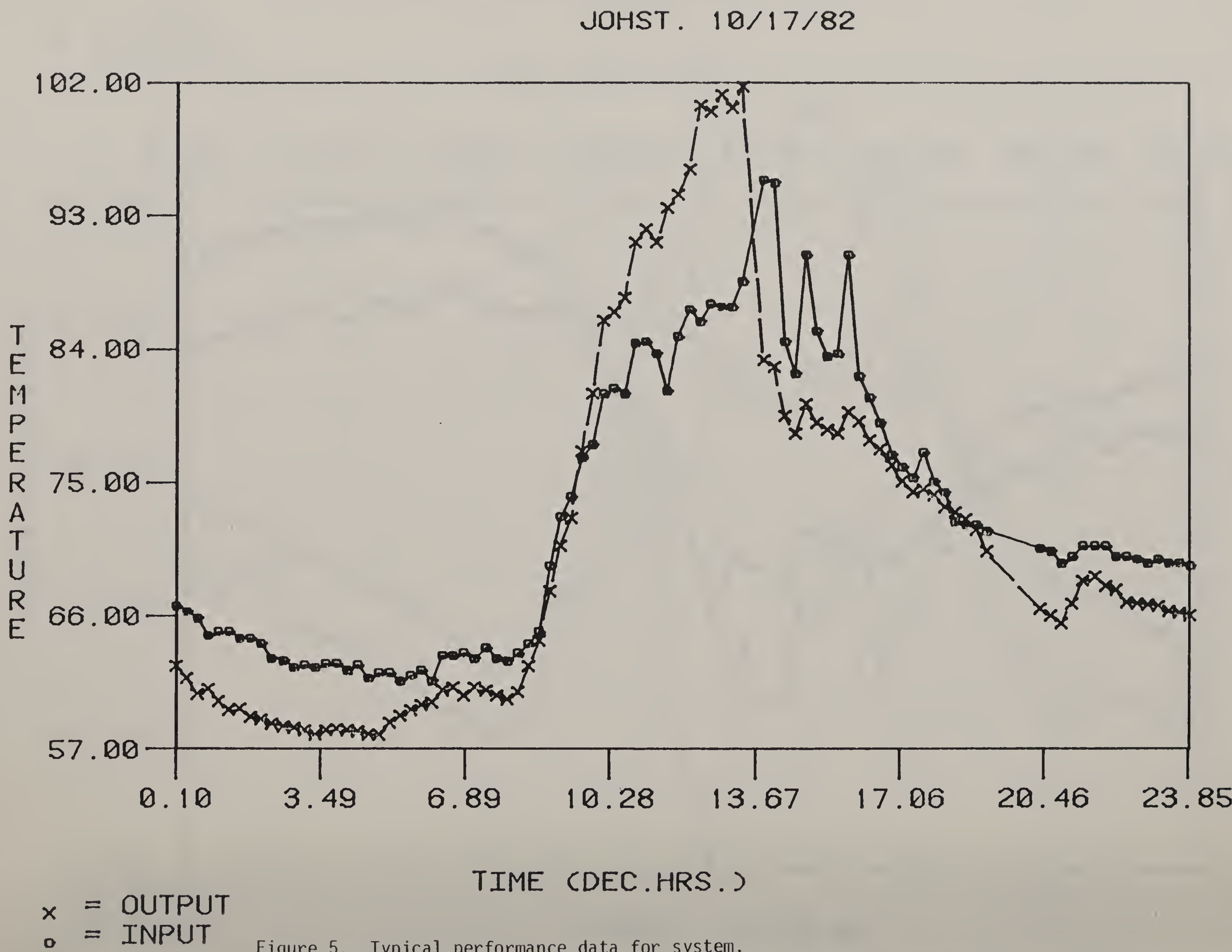

Figure 5. Typical performance data for system.

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December 30, 1982

The Byrnes Farm, Inc. Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, P.E., Project Leader; M. K. Elfino, P.E., Project Engineer

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: The Byrnes Farm, Inc. is located 1-1/2 miles northwest of Hastings, FL, on Federal Point Road (approximate latitude 30°N).

DESCRIPTION OF FARM: The Byrnes farm 225 acres of cabbage (harvested December to April), 450 acres of potatoes (harvested April to June), followed by cover crops which are not harvested. The cabbage is harvested and packed in a cabbage packinghouse for shipment to the fresh vegetable market. The potato packinghouse is an older structure originally used to pack flower bulbs. Through the years several additions have been made and it is not possible to give a simple overall dimension. The construction is basically open pole barn/shed type with a metal roof supported by wooden truss. The outer surface of much of the roof was sprayed with foam insulation to reduce the building heating load as well as waterproof the roof. The machinery line is similar to other packinghouses though much of the equipment has been designed and fabricated in house. The potatoes are brought from the field in tractor pulled trailers. They are dumped from the trailers into a water flume, then spray washed and passed through the machinery line, which is permanently installed in the packinghouse. The surface moisture is removed, after

washing, by brushes, absorbent rollers, and dryer fans. The four (20 in., 3/4 HP, 1725 RPM) dryer fans blow ambient air over the potatoes as they are carried on a roller conveyor through the dryer before the grading operations. The potatoes are bagged in paper bags or boxes and loaded for shipment, primarily for table use. Production each year may be as high as 10 million pounds with a gross price of $500,000 to $1,000,000.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar hot-air system to provide baseload heating for surface drying fruits and vegetables, specifically Florida potatoes.

2. To evaluate a non-conventional solar heated air configuration with regard to collector efficiency and increased drying ability compared to ambient air drying.

3. To provide better surface drying, resulting in less unusable product at the destination point.

4. To secondarily provide a source for winter heating of the packinghouse office.

SOLAR SYSTEM DESIGN:

The traffic around the packinghouse prevented use of a ground mounted solar collector. The age and construction of the packinghouse did not favor incorporation of a collector by modification of the existing roof. The foam insulation sprayed on a portion of the roof (with a 45° slope from horizontal and a southern exposure) and the desire to construct an inexpensive collector inspired a unique collector design. An inflated plastic collector was mounted on the roof. The rectangle shaped collector perimeter was constructed of a wood frame (2 x 4 pressure treated lumber) attached to the roof top. Poly lock strips were connected to the lumber and to hold the plastic collector cover on all four sides. The cover (glazing material) is a 6-mil clear plastic (polyethylene) and the absorber is the foam insulation. One portion of the roof which fell under the plastic cover was uninsulated and was insulated with 3/4 inch 4 x 8 feet sheets of board insulation. The base of the lumber was sprayed with aerosol-type foam insulation to provide a good seal between the lumber and the roof. Two vents were cut in the roof at the west end of the collector and two were cut through the roof under the east end of the collector. The west vents are over a loft area where two inflation fans were installed and connected to the roof vents with flexible duct. The vents over the east end are over the existing dryer fans and flexible duct connect the roof vents to a shroud over the conveyor line. In operation the fans blow air which inflates the plastic collector and the air is heated as it passes through the 1,200 ft^2 collector, then the warm air passes over the potatoes. In the winter the fans will be moved to the east end and blow air toward the office in the

west end of the building. The west end flexible ducts will pass warm air to the office for heat.

CONSTRUCTION COST: The total cost (materials and labor) for this system was \$3,884 for an average cost of \$3.25/ft^2 of collector surface.

PERFORMANCE: The solar drying system at the Byrnes packinghouse is complete and has been operational tested. The system was not in operation during the last potato season and has not been used to surface dry potatoes. Only limited performance data has been collected at present but the performance appears to conform to design performance criteria.

During testing in October 1982, the average solar radiation at the collector site was 1600 BTU/ft^2 based on an 8 hour day. The total radiation for the 1200 ft^2 collector surface was 1.92 x 10^6 BTU/day. The average air flow through the system was 5600 cfm. The average temperature rise was 20°F. The average relative humidity during the test period was 85%. The average energy gained by the heated air was 0.968 BTU/day, resulting in an efficiency of 50%. The equivalent heating provided by L.P. gas would require 10.75 gallons and based on a cost of \$1.00 per gallon, the amount of savings was \$10.75/day. The potato packing season is estimated to be 90 days. A simple cost analysis indicates a payback period of 4 years. When the project was briefly tested at the end of May 1982, the temperature rise was 32°F and the efficiency was 62%.

Figures 3, 4, 5 and 6 show typical performance data. Additional data collection is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: University of Florida personnel installed the solar collector system with assistance from Byrnes Farm labor. Due to the condition of the roof (45° slope, old, irregular, etc.) it was difficult to construct the wood frame. The pressure treated lumber used for the frame should have been of higher quality since warping caused considerable problems. Leakage of air beneath the frame required additional work for sealing to minimize escape of heated air. The aluminum poly lock expanded when heating resulting in buckling. Allowance for expansion must be made at the end of each piece and at screw holes. The initial plans called for a single sheet of clear plastic collector cover and the roof surface was not to be painted black. Construction was attempted with a single clear plastic cover with a black plastic sheet laying flush on the top of the roof surface. The temperature rise in the collector caused the clear plastic cover to fuse to the black plastic. Next the roof surface was painted black and a double thickness clear plastic cover was used. Again, the temperature of the collector caused some deterioration of the interior plastic sheet. Use of a single clear plastic cover and a flat black painted surface was successful. Considering the obstacles encountered the construction was of adequate quality.

Future use of the collector for surface drying of potatoes is uncertain. The Byrnes recently completed a new more modern potato packing-

house. The old packinghouse will only be used as a backup. Interest was expressed concerning adaptation of the solar drying system to the new packinghouse, but this is not possible since the system was tailored for the unique circumstances related to the old packinghouse. Because of the construction of the new packinghouse, interests in the project by the Byrnes has been reduced.

The solar drying system is a unique example of how an inflated-plastic covered-plate collector can be added to the roof of an existing structure. During periods when the inflation fans are not in operation, no problems with the temperature rise was encountered and no visible effect on the clear plastic was observed. A support system is under consideration, made of 1/2 inch PVC pipes, to support the clear plastic and keep it away from the black painted, insulated roof when the fan is not in operation.

The future use of the demonstration is uncertain but efforts to continue evaluation of the system are planned and further data collection and analysis will be studied for possible system operation and design improvements.

For more information contact:

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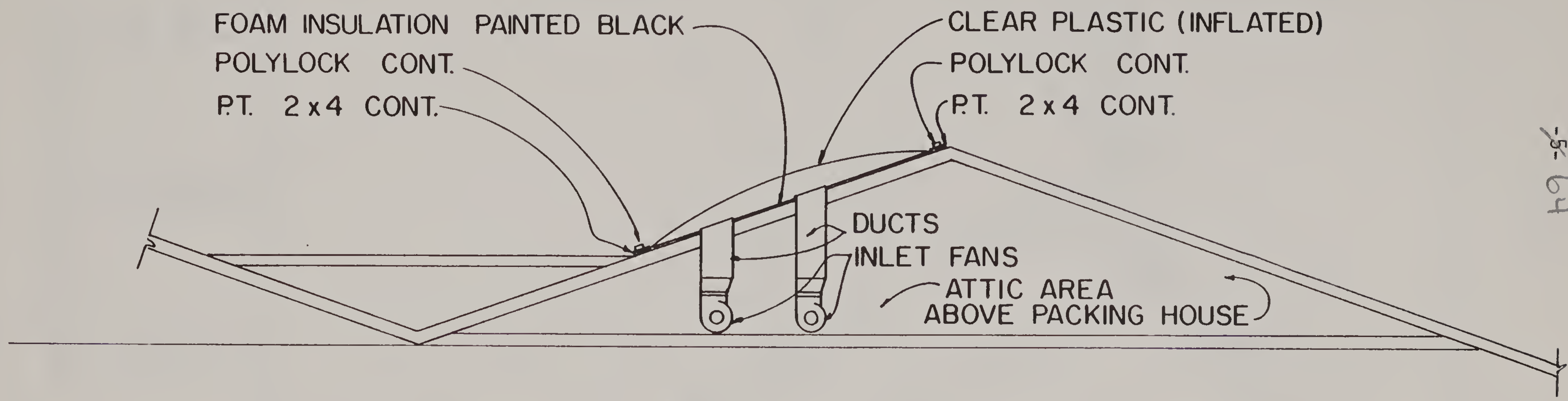


Figure 1. Diagram of cross-sectional construction detail.

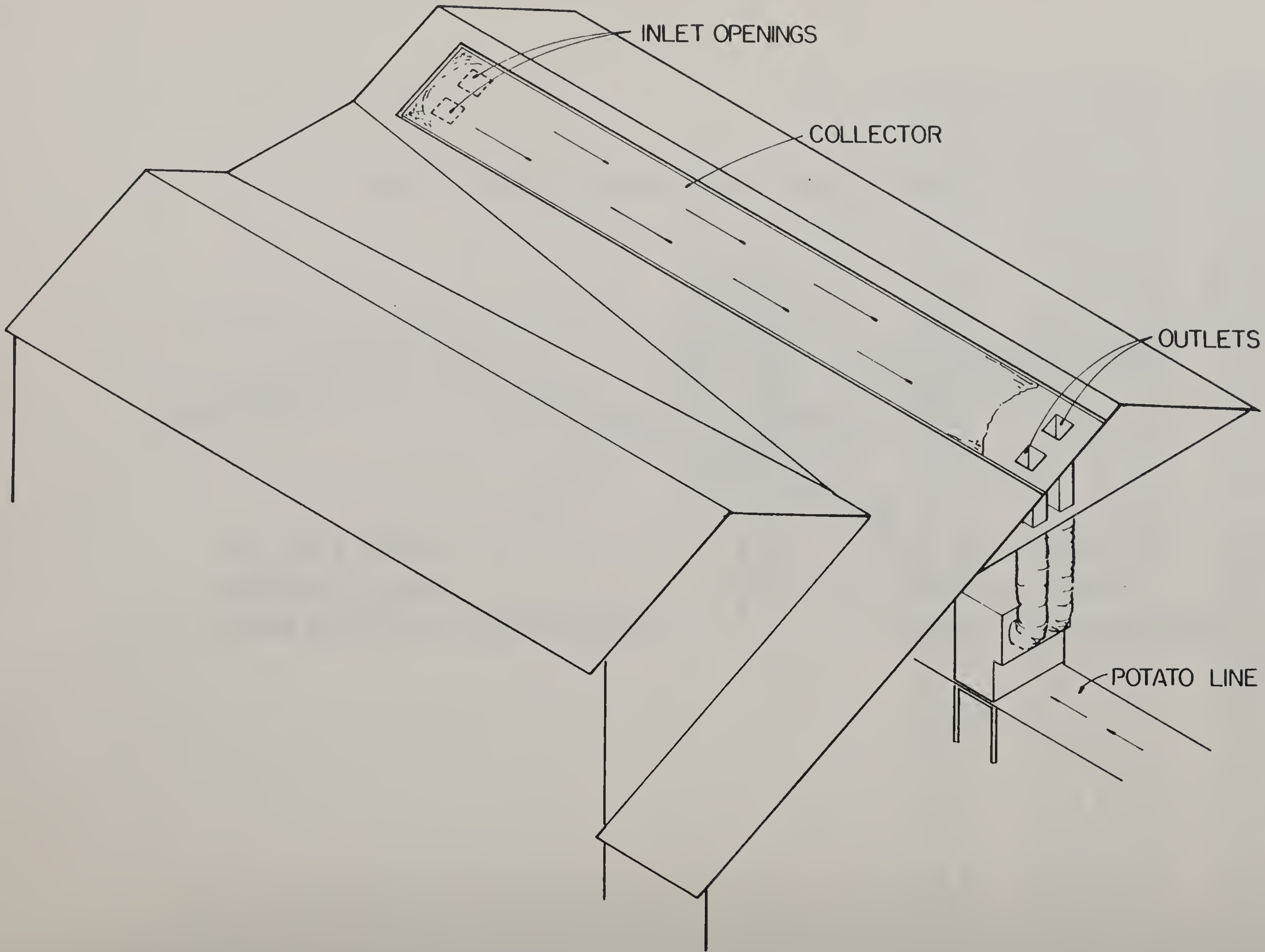


Figure 2. Diagram of air flow through the system.

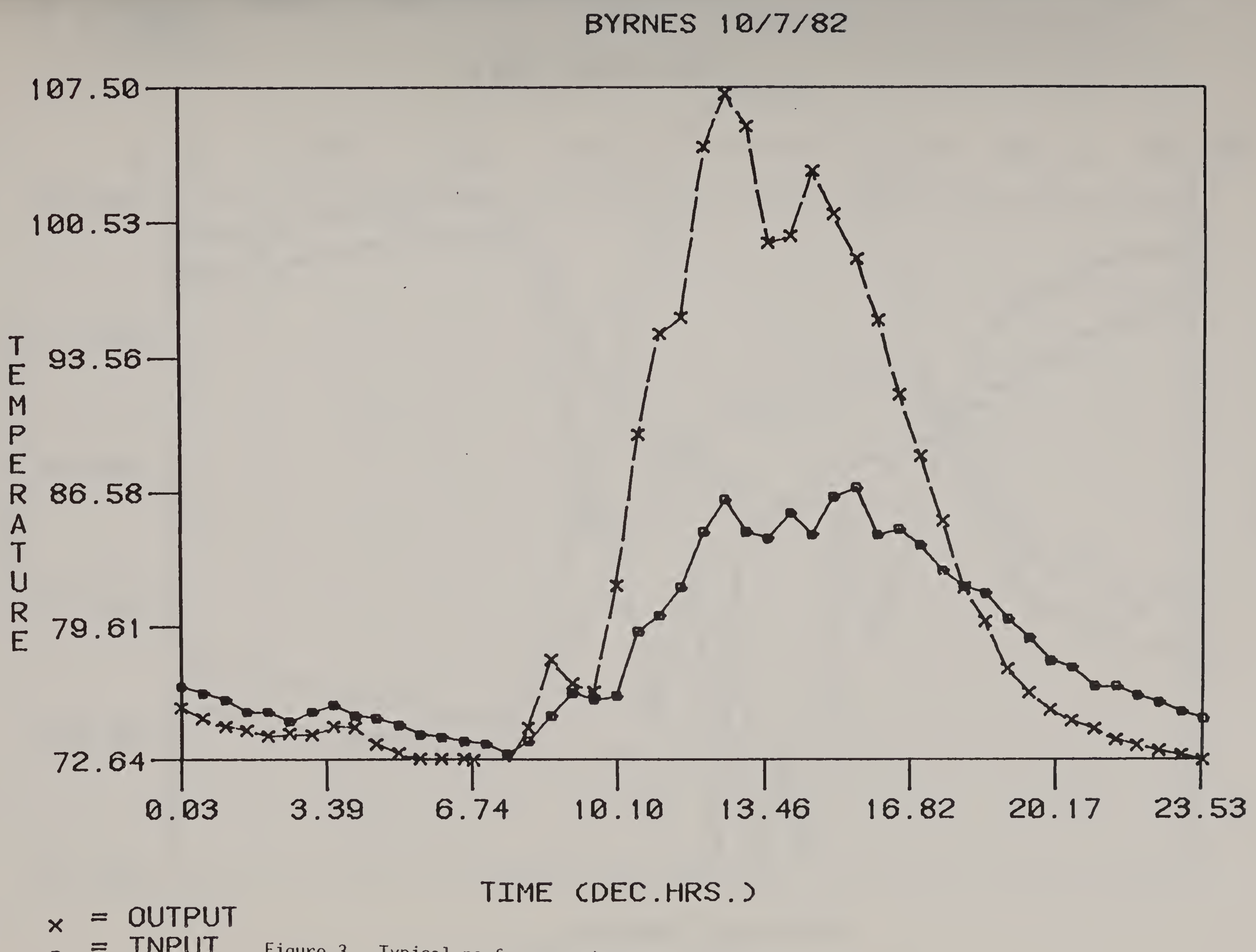


Figure 3. Typical performance data for system.

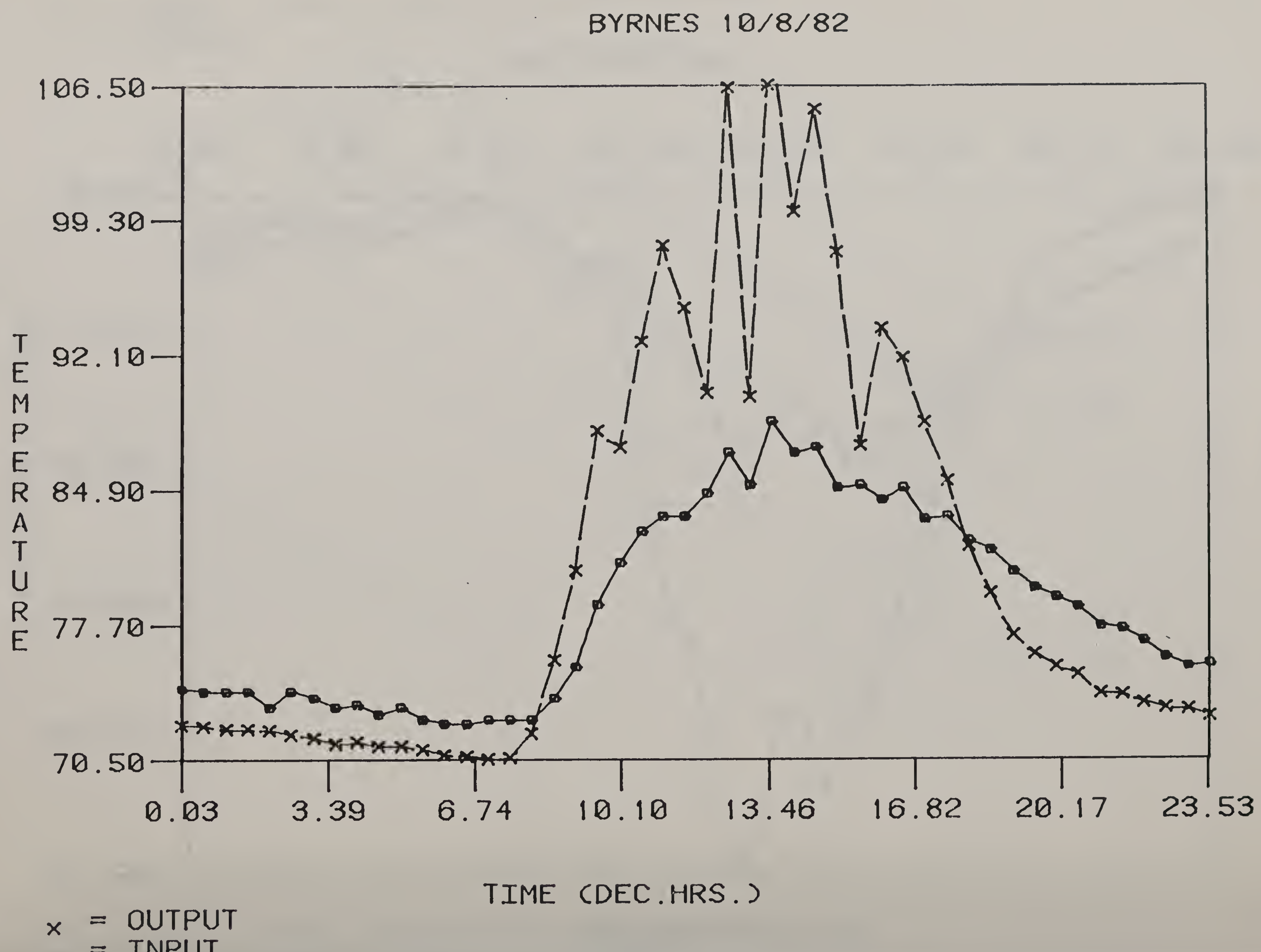
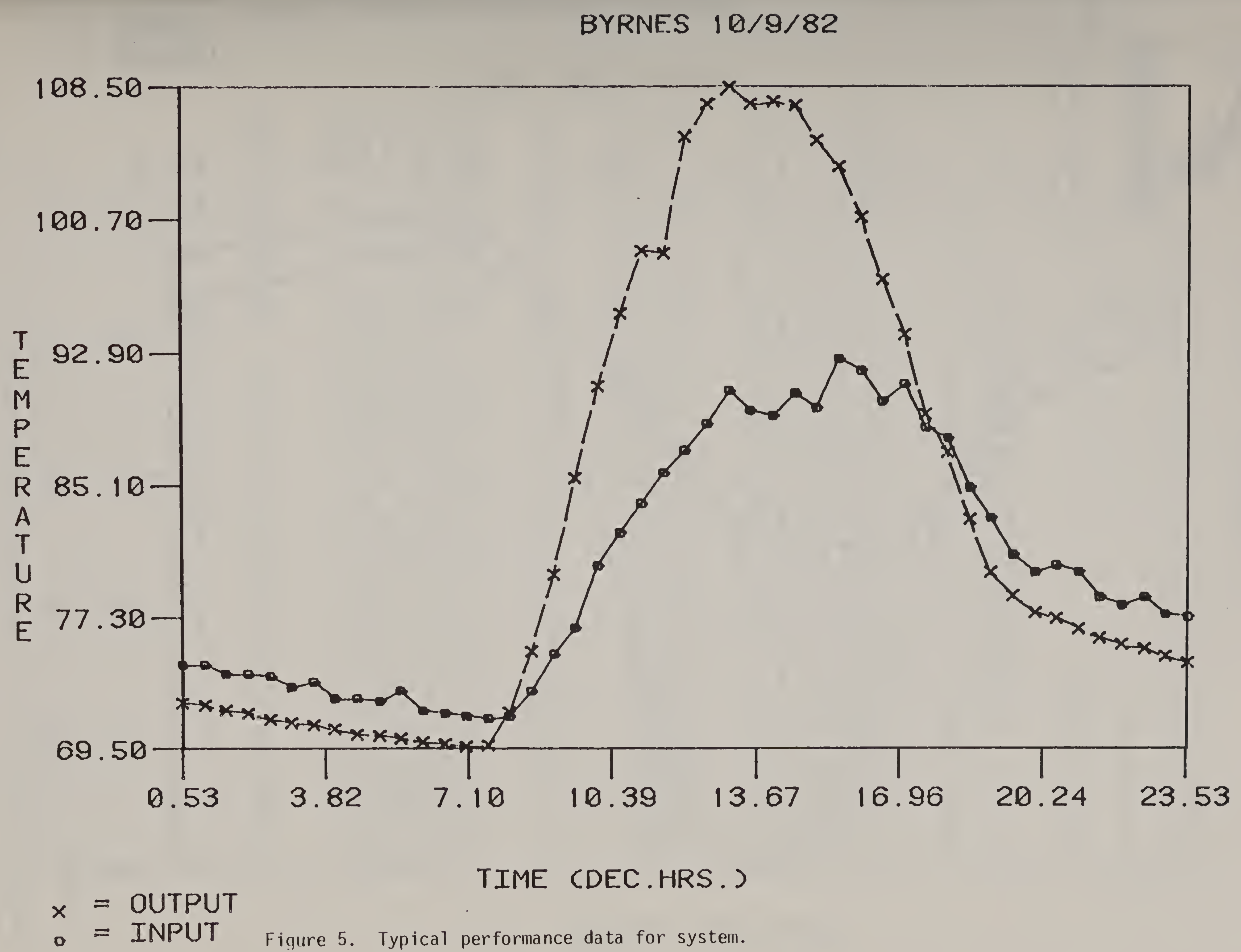


Figure 4. Typical performance data for system.



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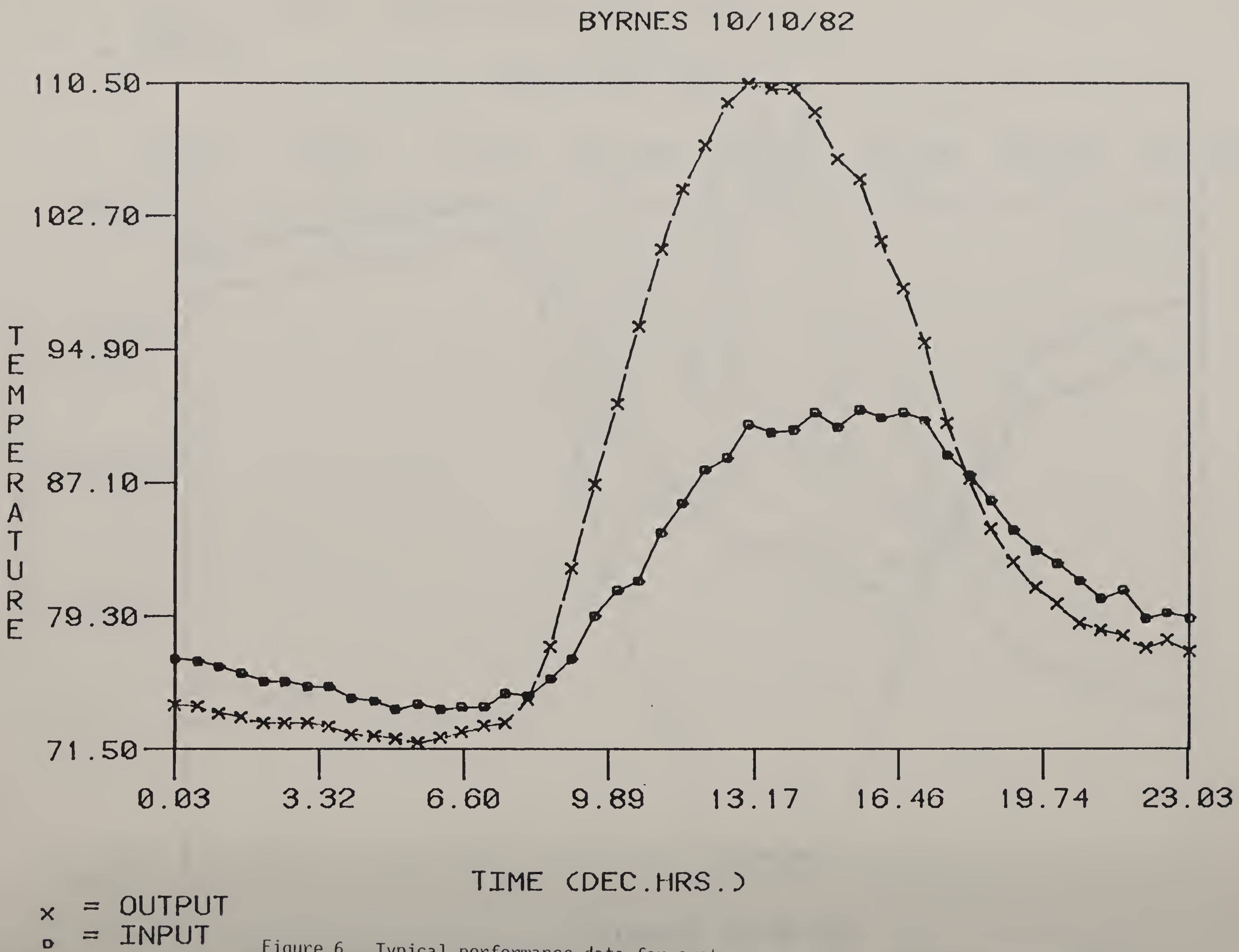

Figure 6. Typical performance data for system.

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December 30, 1982

D. A. Lewis, Jr. Farm Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, P.E., Project Leader; M. K. Elfino, P.E., Project Engineer

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: The D. A. Lewis Jr. farm is located near Ocala, Florida, 1-1/2 miles north of Anthony, Florida (approximate latitude 29°N).

DESCRIPTION OF FARM: Mr. Lewis farms about 600 acres, producing corn, grain sorghum, peanuts, soybeans, pasture/hay and cattle. The grain drying facilities consist of two 5200 BU grain bins and one 6,000 BU grain bin, each using a 7 HP fan and L.P. gas heater. The corn and sorghum are dried in July and August while the soybeans are dried in October and November. The peanut drying facilities consist of five 5-ton drying wagons and L.P. gas blower/heaters capable of drying four wagons at a time.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar preheat system to reduce fossil fuel consumption during conventional grain drying.

2. To determine the efficiency of collecting solar energy with a covered-plate collector, incorporated in the roof during construction of a new building, used as a preheater for crop drying wagon/drying fan system and supplementally, as a pre-heater for grain bin drying system, and establish the percent of drying energy available from this source.

SOLAR SYSTEM DESIGN: The collector selected is basically a covered-plate collector. It is a part of the roof of a newly constructed equipment barn. The size of the solar collector is 18' x 100' (1,800 ft^2) with the collector facing south. The air is delivered at the enclosed inlet end of the collector using a fan (propeller type, 14,400 cfm, 0.5" S.P, 3 HP). The collector is connected to a distribution box using insulated plywood duct. This distribution box will supply the hot air to a drying fan for two peanut wagons (5' x 8' x 14'). The collector will also be ducted to the corn bin which is located 23 ft away from the collector. Figures 1 and 2 show construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was $4,388 for an average cost of $2.44/$ft^2$ of collector surface.

PERFORMANCE: The solar drying system on the Lewis farm is complete and in operation. The system has been used to dry grass seed and peanuts and has functioned well to date. Mr. Lewis is pleased with the system and indicates he has already received some economic return. Only limited performance data has been collected at present but the performance appears to conform to design performance criteria.

During testing in October 1982, the average solar radiation at the farm location (during peanut drying season) was 1260 BTU/ft^2 based on an 8 hour day. The total radiation for the 1,800 ft^2 collector was 2.268×10^6 BTU/day. The air flow through the system was 5,400 cfm. The average temperature rise was 20.5°F. The average energy gained was 0.952×10^6 BTU/day, resulting in an efficiency of 42%. The average relative humidity during the test period was 85%. The equivalent heating provided by L.P. gas would require 10.6 gallons and based on a cost of $1.00 per gallon, the amount of savings was $10.60/day. The drying season for peanuts and other crops grown on the farm is estimated to be 180 days. A simple cost analysis indicates a payback period of under 3 years.

Figures 3 and 4 show typical performance data. Additional data collection is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: Initially the system on the Lewis farm was to be an inflated-plastic hot-air collector. Since he decided to build a new equipment barn, the Florida Plan Service provided construction plans which included incorporation of a covered-plate collector. Mr. Lewis contracted a barn construction company to build the barn and they also constructed the collector. This was the contractor's first exposure to solar collection and he expressed considerable interest.

The construction was of high quality. There has been a problem with rain leaking through the fiberglass laps. This is due to insufficient overlap and inadequate sealing. Also high quality fiberglass should be used at a slightly higher cost. The enclosed attic could be better insulated using 3/4-inch foam board type insulation. Styrofoam sheet was used but inside the enclosed attic it eventually deteriorated.

Mr. Lewis is pleased with his system and the demonstration is a good example of how solar collection systems can be installed during new building construction. No major design changes are planned but, further data collection and analysis will be studied for possible system operation and design improvements.

For more information contact:

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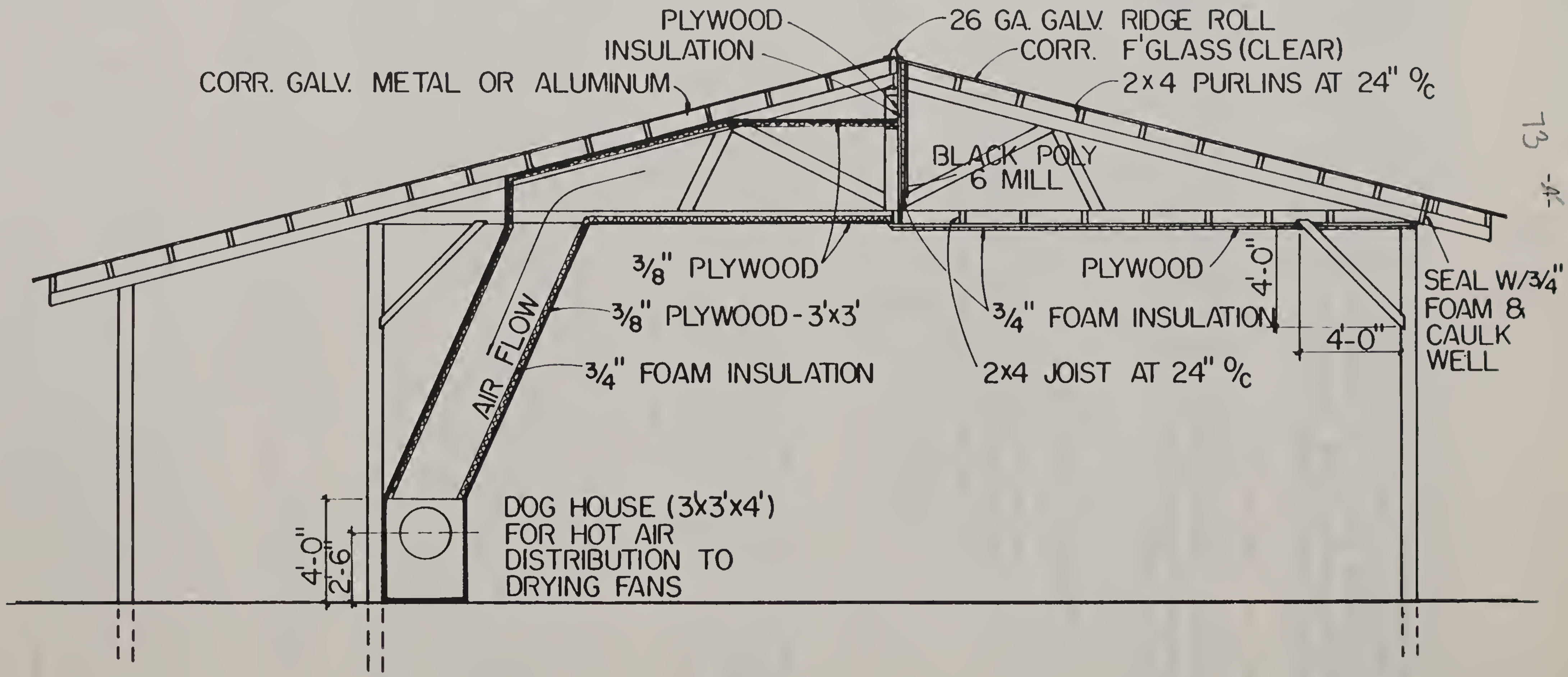

Figure 1. Diagram of cross-sectional construction detail.

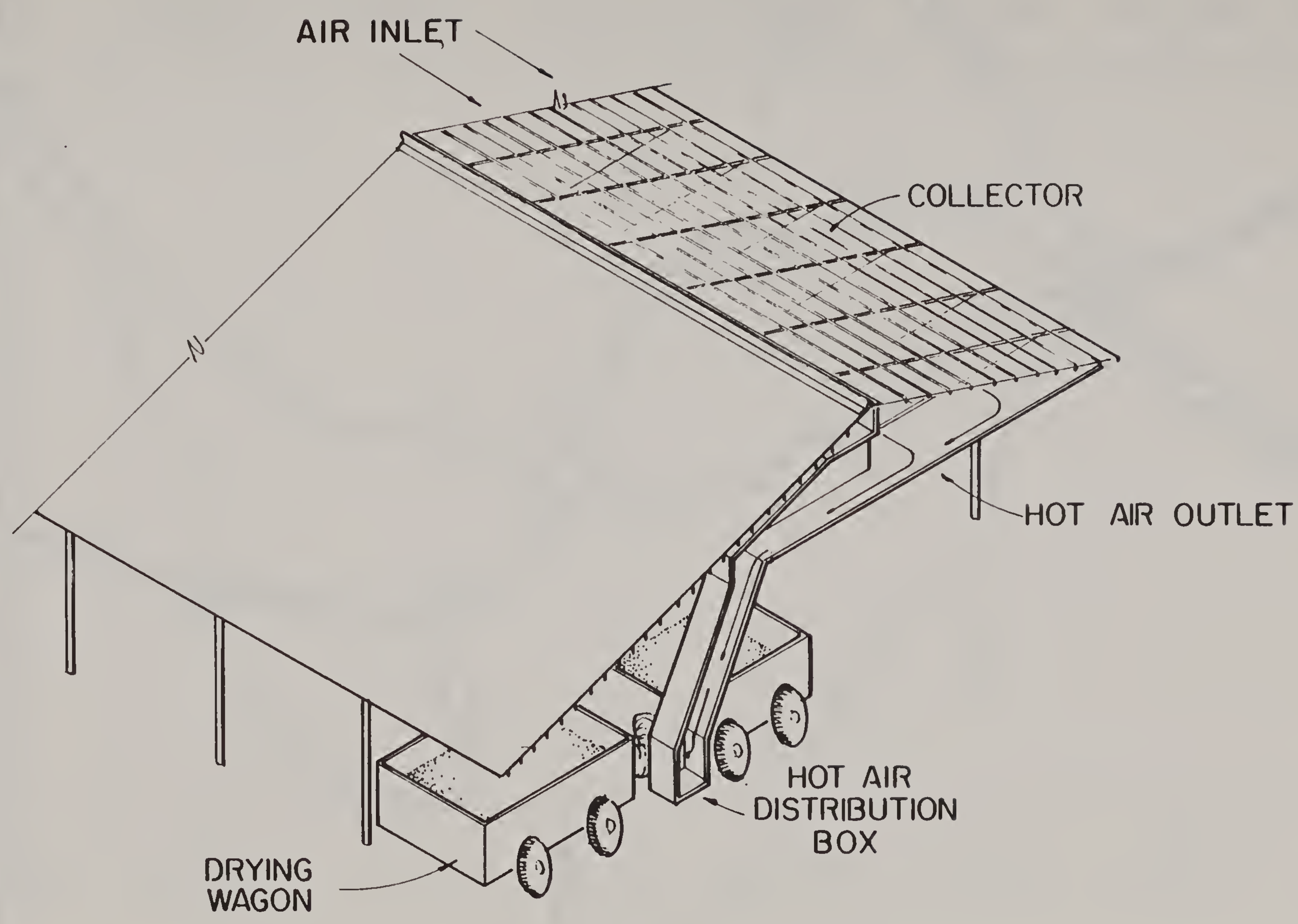

Figure 2. Diagram of air flow through the system.

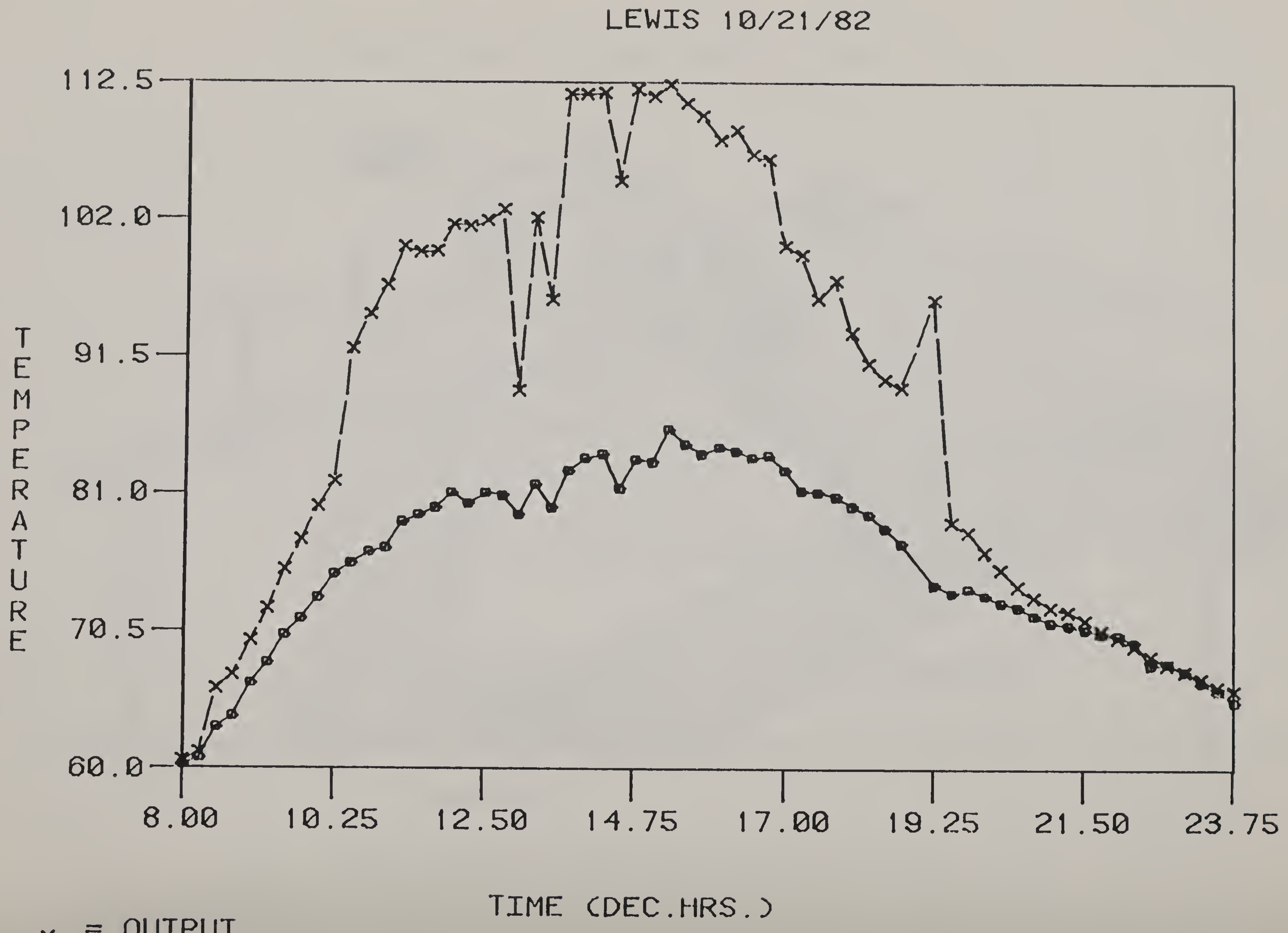

Figure 3. Typical performance data for system.

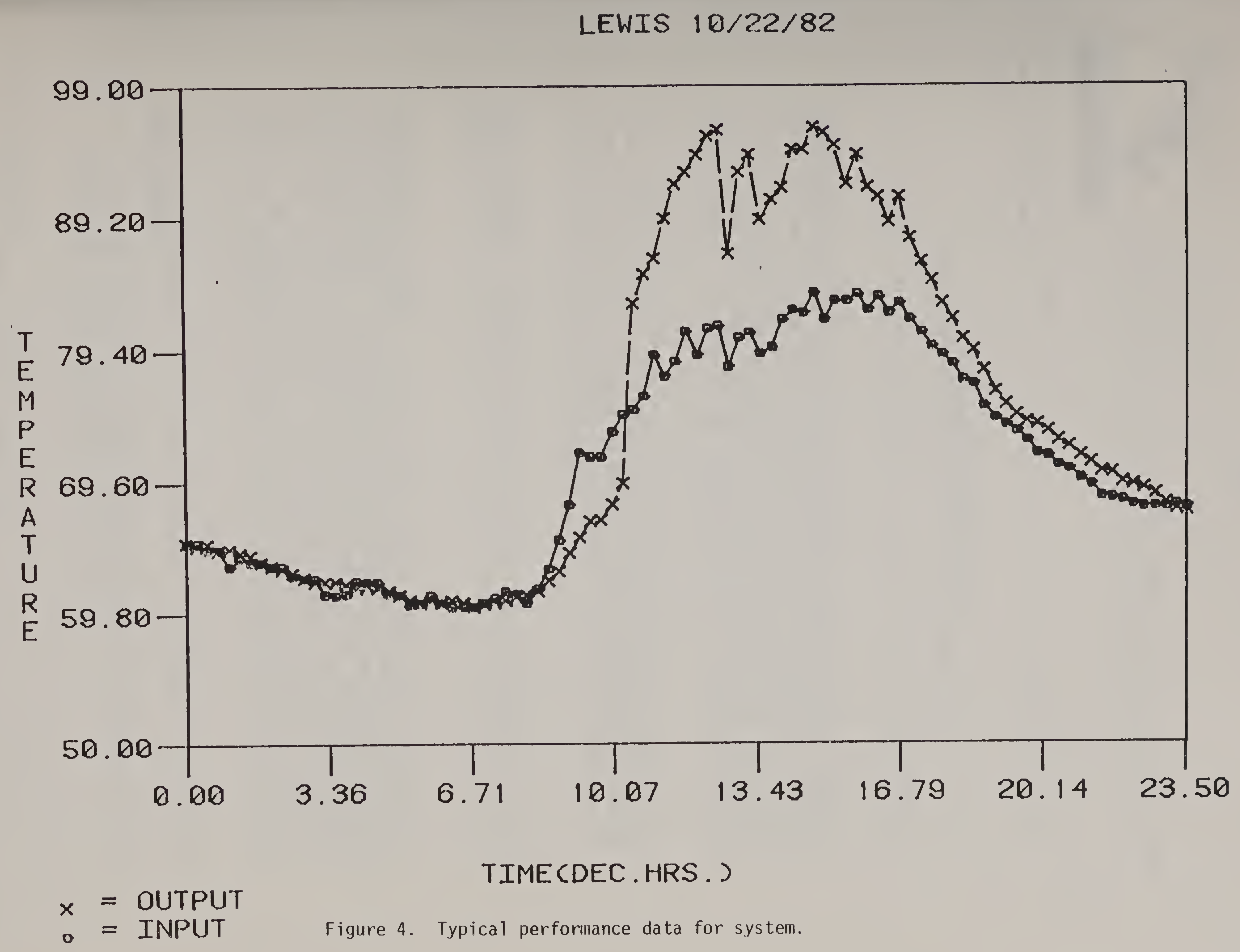

Figure 4. Typical performance data for system.

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December 30, 1982

Ray Gay Farm Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, P.E., Project Leader; M. K. Elfino, P.E., Project Engineer

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: The Ray Gay Farm is located near Lake City, FL, 1-1/2 miles south of Providence, FL, on State Road 245 (approximate latitude 30°N).

DESCRIPTION OF FARM: Mr. Gay raises feeder pigs from a 50-head herd, farms 150 acres of irrigated corn, and grows small acreage of tobacco and various vegetables. The swine facility consists of two farrowing houses and exterior pens. The grain drying facility consist of a 10,000 bushel grain bin with a 7-1/2 HP fan and L.P. gas heater. The farrowing houses are close to the grain bin. Corn is harvested at a moisture content of 22% w.b. and dried to 13% w.b. Aproximately 1,000 bushels is loaded per layer, the frequency of loading varies. No record of last years drying cost are available.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar preheat system to reduce fossil fuel consumption during conventional grain drying.

2. To determine the efficiency of collection solar energy with a plastic hot-air collector used as a preheater and establish the percent of drying energy available from this source.

3. To be able to provide heat for the farrowing houses during the winter season using the plastic collector.

SOLAR SYSTEM DESIGN: The two collectors selected are basically plastic flat-plate collectors, each 20 by 90 feet. They are oriented in an east-west direction. A wood frame (2 x 4 pressure treated lumber) is to provide the main structure of the collector. The collector is covered with 6-mil clear plastic (polyethylene, the glazing material) and the floor is covered with 6-mil black plastic (polyethylene, the glazing material) and the floor is covered with 6-mil black plastic (polyethylene, the absorber). Between the black plastic and the clear plastic, there is a layer of shade cloth (black polypropylene) with 47% opening. The shade cloth is supported by a plastic tube placed in the middle of the collector and it runs the entire length of the collector. The plastic tube is inflated during operation to keep the shade cloth suspended. A locking system, made out of wood strips, will be used to attach the clear plastic to the frame. The air is delivered at the inlet end of the collector using an inflation fan (propeller type, 8,460 cfm, 0.5" s.p., 1-1/2 HP). The two collectors are connected together by a ducting system and a transition box with adjustable gates for controlling air flow. Figures 1 and 2 show construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was $4,400 for an average cost of $1.22/ft^2 of collector surface. Due to constructing two collectors, two inflation fans and additional ducting were required, resulting in a higher cost compared to a single collector with twice the length. Space limitations necessitated the dual collector design.

PERFORMANCE: The solar drying system at the Gay farm is complete and has been operational tested. The system has not been used to dry corn although it was in operation during the corn drying season. Only limited performance data has been collected at present but the performance appears to conform to design performance criteria.

During testing in November 1982, the average solar radiation at the farm location was 800 BTU/ft^2 based on an 8 hour day (cloudy days). The total radiation for the 3,600 ft^2 collector was 2.88 x 10^6 BTU/day. The average air flow through the system was 8,000 cfm. The average temperature rise was 18°F. The average relative humidty was 80%. The average energy gained by the heated air was 1.244 x 10^6 BTU/day, resulting in an efficiency of 43%. The equivalent heating provided by L.P. gas would require 13.8 gallons and based on a cost of $1.00 per gallon, the amount of savings was $13.80/day. The time this solar system could be utilized for drying corn in the summer and heating the pig nursery in the winter is estimated to be 3 months/year. A simple cost analysis indicates a payback period of less than 2 years.

Figures 3 and 4 show typical performance data. Additional data collection is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: Mr. Gay used available farm labor to install the solar collection with assistance from University of Florida personnel. This was the first collector of this size and type constructed in the State and some construction problems arose but on-site corrections resulted in adequate construction quality. There was a problem with the collector lifting off the ground when inflated. This resulted from a combination of inadequate construction techniques in installing the anchoring system and over design of the inflation fans. The construction crew did not install the wood anchor post to a depth as specified in the construction plans. To correct this problem holes were dug and a tee was attached to the base of the post which produced a deadman effect when the holes were filled and compacted. An adjustable curtain was attached to the fan inlet box to partially block the inlet in order to reduce the uplift after the collector was fully inflated. Lack of care during construction also resulted in many holes and tears in the plastic cover which were adequately patched with special tape designed to seal holes in this type plastic.

The wiring of the inflation fans required more effort and electrical materials than anticipated. The amount of energy required to maintain inflation was too great to keep the collectors inflated continuously during the drying as initially proposed. The desire to keep the collector inflated was to prevent damage as a result of wind whip, etc. Rather than just let the plastic cover completely deflate when the inflation fan was not on, a vinyl covered cable was installed between the inlet and outlet end frames to support the clear plastic and prevented the clear plastic from fully touching the shade cloth or black plastic. This system of support worked adequately with no apparent problem with the clear plastic. The solar radiation collection was reduced by deposition of dust and debris due to farm operating conditions, which was difficult to clean.

Mr. Gay did not have corn to dry during the last drying season. He hopes to use the system to dry corn during the next drying season and during this winter to help provide heat to his pig nursery. This demonstration is a good example of how solar collection systems can be constructed with low cost materials and a design which requires minimal construction skills. No major design changes are planned but, further data collection and analysis will be studied for possible system operation and design improvements.

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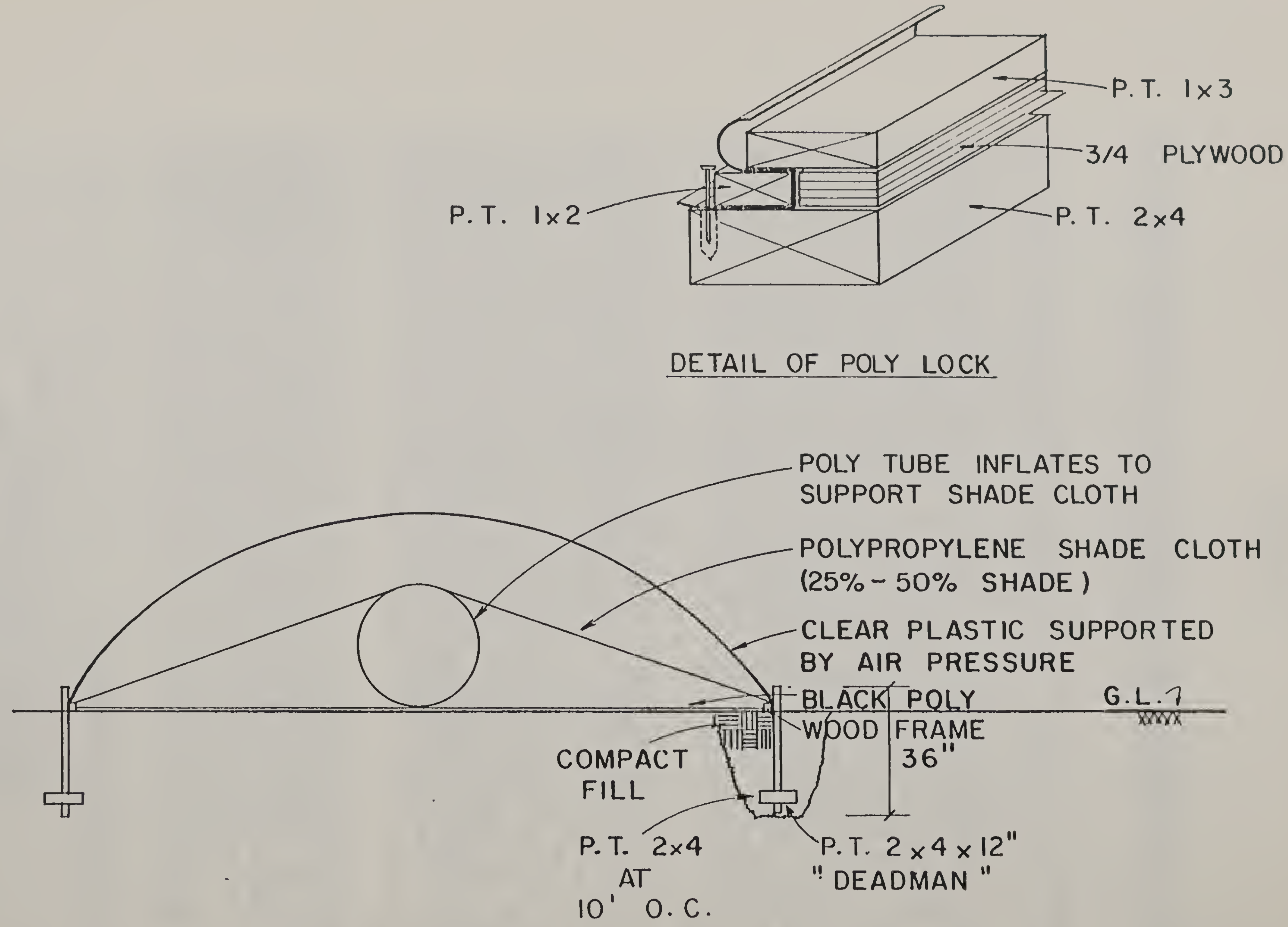

Figure 1. Diagram of cross-sectional construction detail

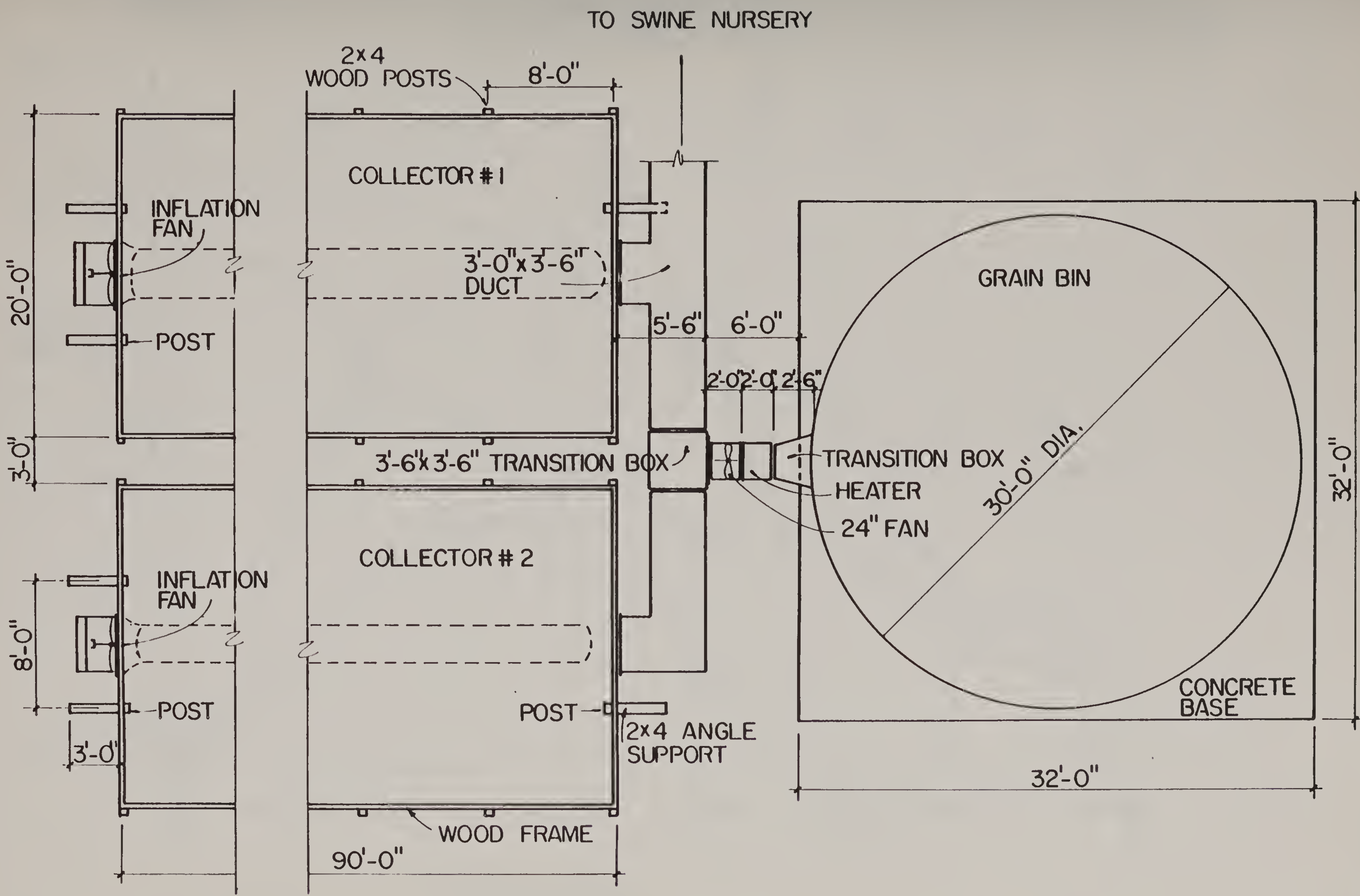

Figure 2. Diagram of plan construction detail.

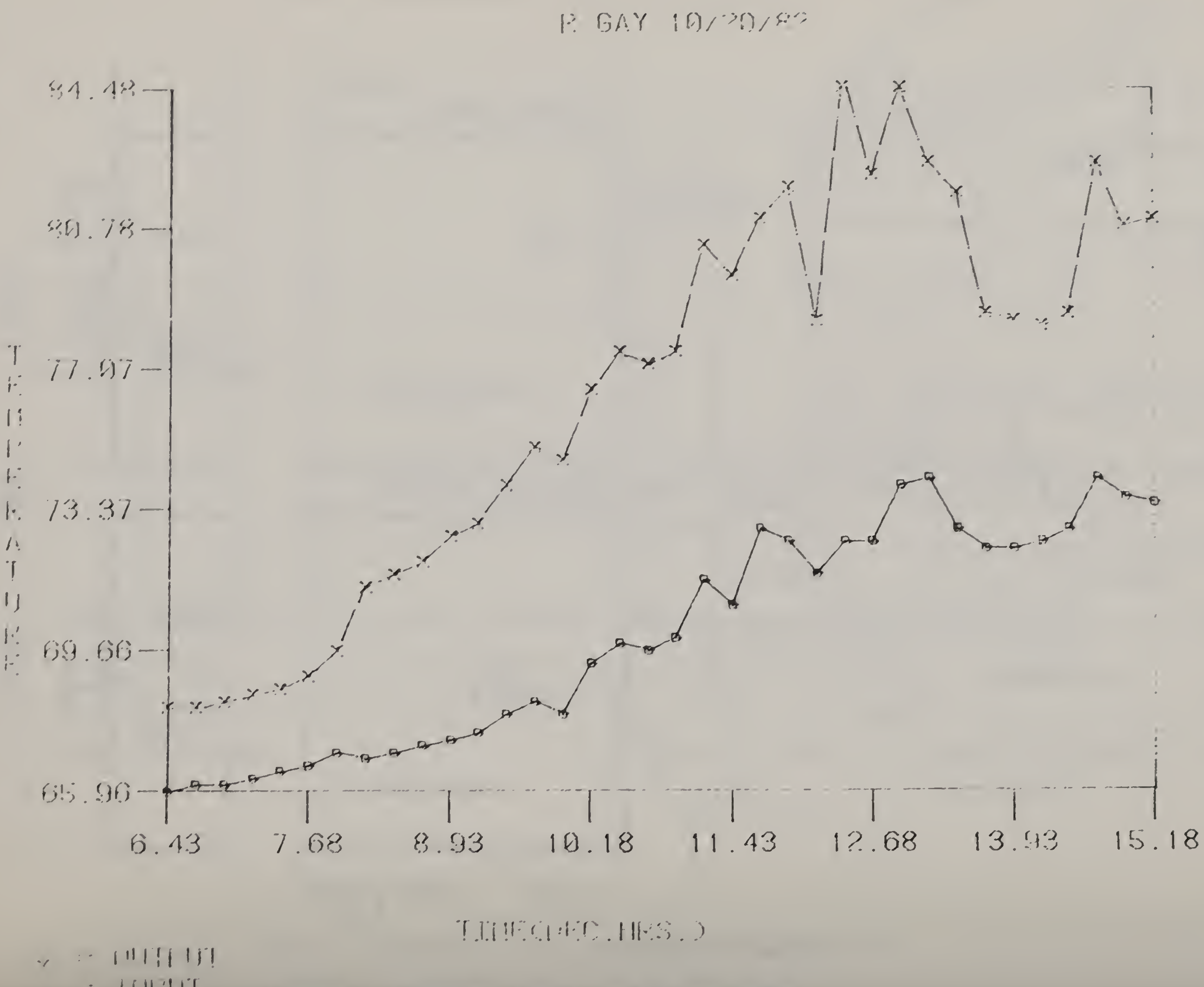

Figure 3. Diagram of typical system performance.

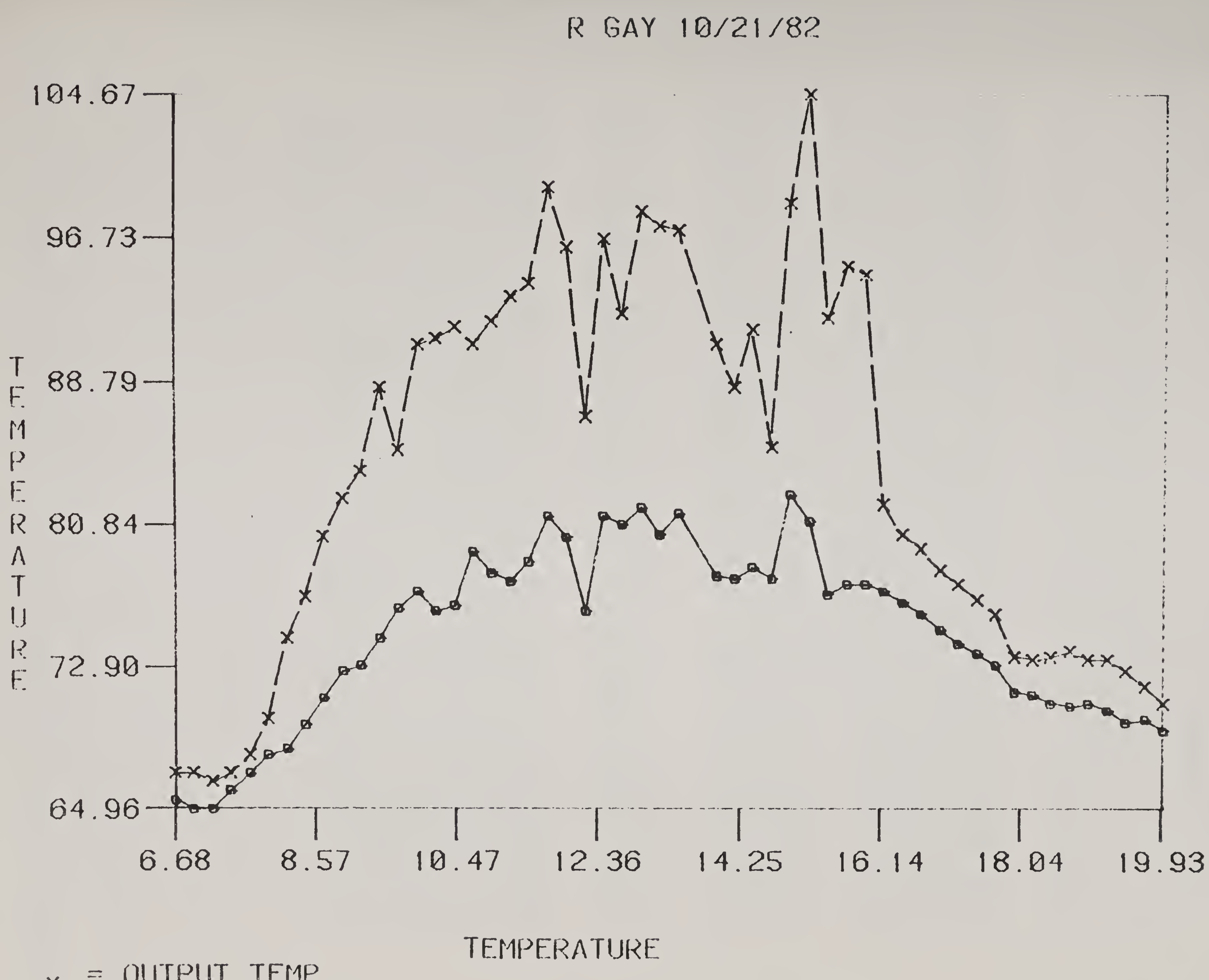

Figure 4. Diagram of typical system performance.

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December 30, 1982

Summer's Harvest Seed Company Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, ~~P.E., Project Leader~~; M. K. Elfino, P.E., Project Engineer

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: Summer's Harvest Seed Company (formerly Dasher Seed Drying) is located Southwest of Live Oak, FL, on State Road 252, 3 miles East of the intersection with State Road 51 (approximate latitude 30°N).

DESCRIPTION OF FARM: Summer's Harvest Seed Company provides complete processing of all seeds (drying, cleaning, bagging, etc.) and 16,000 ft^2 of storage. The facilities include two large metal warehouses, a grain elevator, scales, drop chute, seed cleaner, bagging machine, etc. The drying facilities include a 15-bay 20 x 225 ft drying shed, Peerless All Crop drying trailers and 5-7 HP jet dryers. Some of the 100,000 BU of grain processed last year were cow peas, rye, oats, various grass seeds, and soybeans. The seed drying season normally runs May to December. To conserve energy and reduce cost more, forced (without heat) ambient air is being used increasingly and more intense drying management is being practiced.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar hot-air system to provide pre-heating (or base load heating) for seed drying.

2. To evaluate a conventional solar heated air configuration with regard to collector efficiency and percent drying load available from solar.

3. To evaluate solar fabrication materials for a moderate industrial environment in a high solar intensity climate.

SOLAR SYSTEM DESIGN: A portion of the N-S oriented drying shed roof was used to build a covered plate collector. Eight air channels were created (each 50 ft long) with nominal 2 x 6 in. spacers (2.5 ft on center) and a UV-treated fiberglass (Kalwall) cover installed. Polyisocyanurate sheet insulation was added beneath the existing roof purlins to reduce heat losses. A 2.5 ft by 20 ft hole was cut across the metal roof and this hole was connected to a duct which channels air to the dog house at the fan entrance. A jet dryer which can dry two wagons at a time (double plenum box) is used. The dryer fan pulls ambient air in the opening beneath the north end of the Kalwall, through the eight 2.5 ft wide by 50 ft long air channels (1,000 ft^2), down through the metal roof slot, through the connector duct, through the dog house, and finally force the air through the seed in the drying wagon. Supplemental heat is available by the thermostaticallly controlled L.P. burner of the existing jet dryer. Figures 1 and 2 show construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was \$5,400 for an average cost of \$5.40/ft^2 of collector surface.

PERFORMANCE: The solar drying system at the Summer's Harvest Seed Company is complete and in operation. The system was used to dry grass seed and cow peas and has functioned well to date. The Summer's people are pleased with the system and indicate that a comparison of the solar drying system with the existing L.P. gas drying system, results in the same performance with only an additional two hours per drying wagon required by the solar system. Performance data collected indicates the performance conforms to design performance criteria.

During testing in November 1982, the average solar radiation at the drying shed was 1,860 BTU/ft^2 based on an 8 hour day. The total radiation available for the 1,000 ft^2 collector was 1.86 x 10^6 BTU/day. The air flow through the system was 7,000 cfm. The average temperature rise was 20°F. The average relative humidity during the test period was 65%. The average energy gained by the heated air was 1.209 x 10^6 BTU/day, resulting in an efficiency of 65%. The equivalent heating provided by L.P. gas would require 13.44 gallons and based on a cost of \$1.00 per gallon, the amont of savings was \$13.44/day. The drying season for the Summer's operation is about 180 days/year. A simple cost analysis indicates a payback period of under 3 years.

Figures 3 and 4 show typical performance data. Additional data collection is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: Summer's personnel constructed the solar collector and this construction was of superior quality. No significant problems have been encountered. The Summer's management is pleased with their system and the demonstration is a good example of how covered-plate solar sollection systems can be retrofitted to existing building. No major design changes are planned but, further data collection and analysis will be studied for possible system operation and design improvements.

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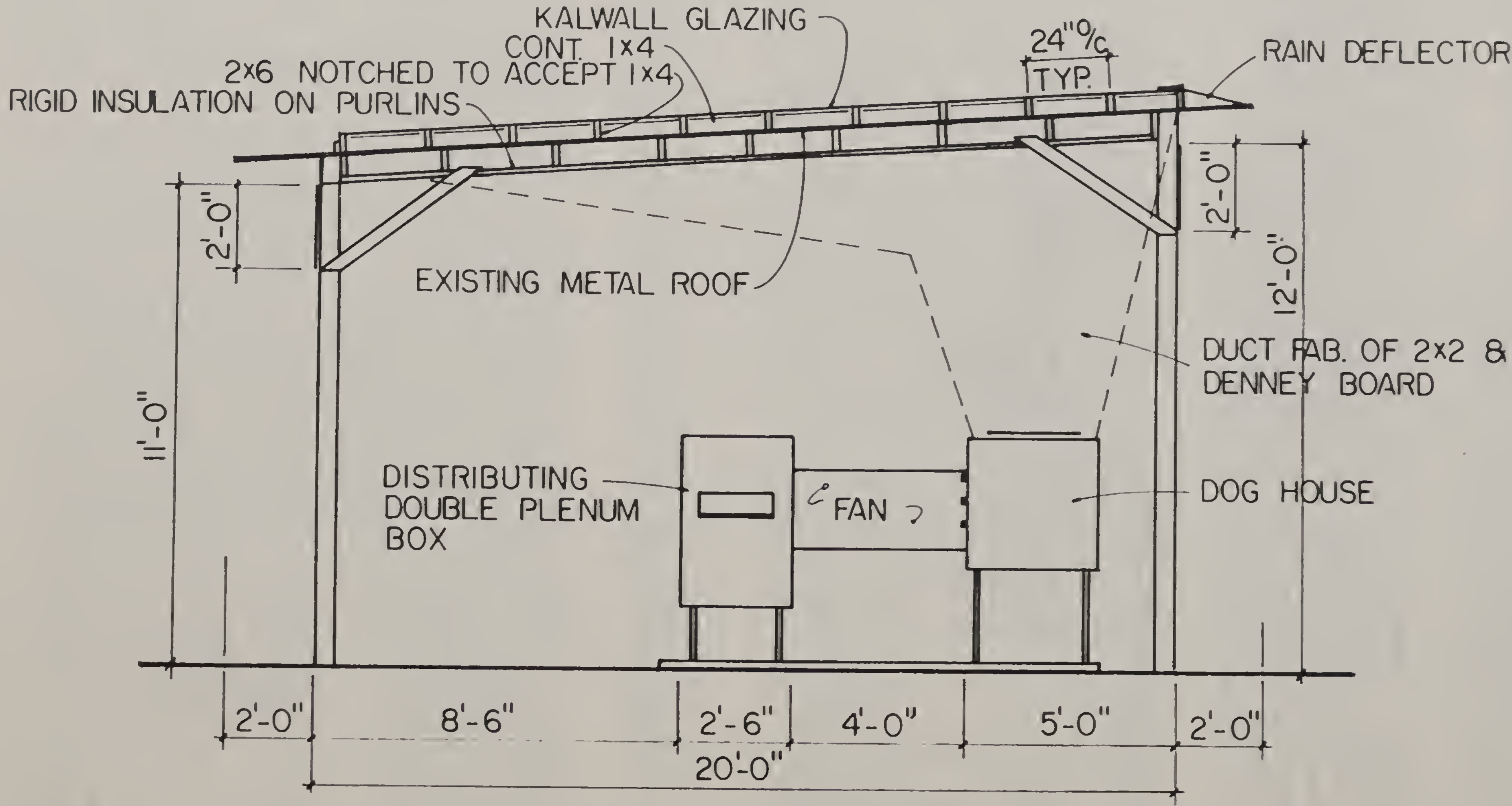

Figure 1. Diagram of cross-section construction detail.

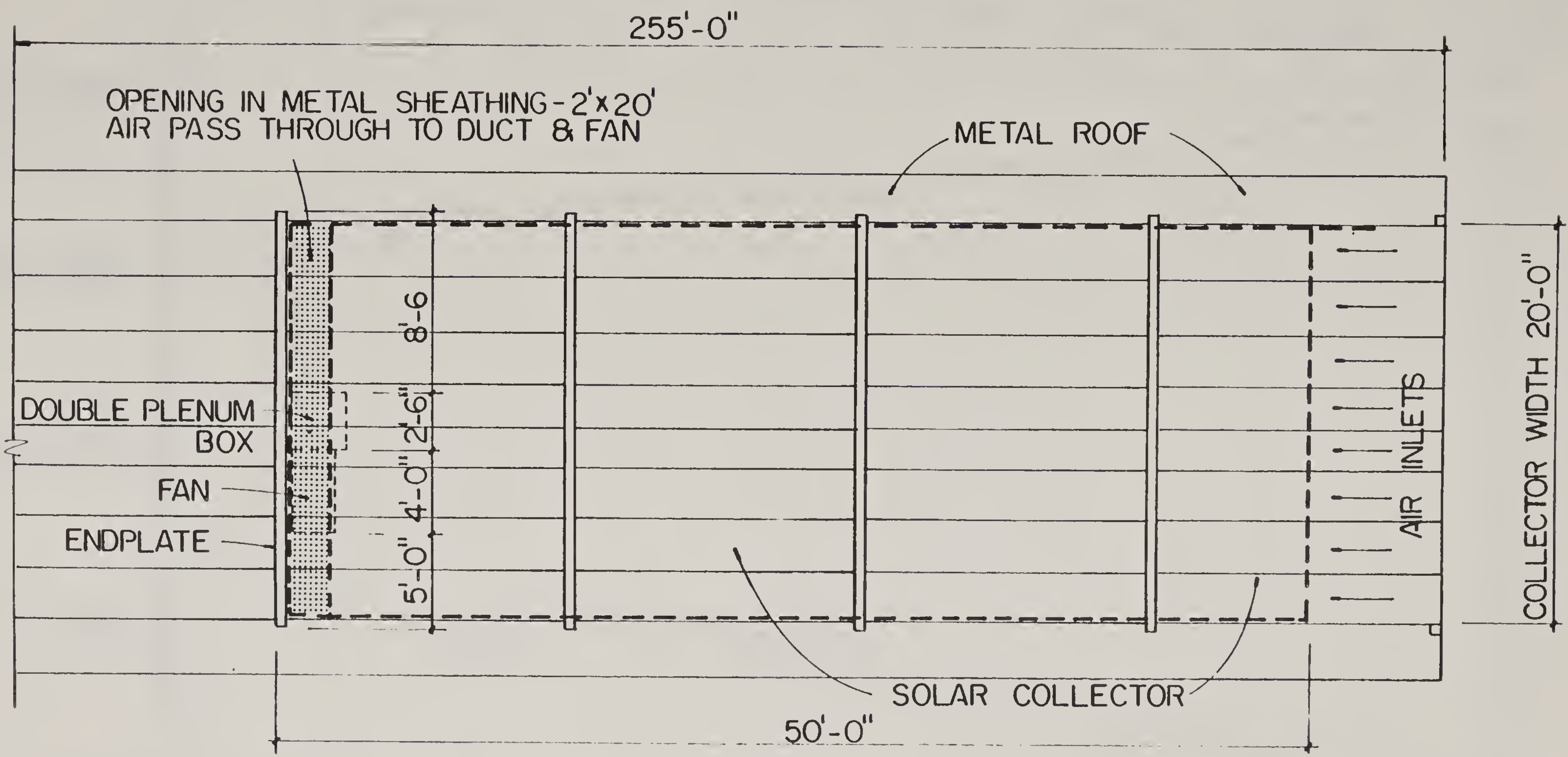

Figure 2. Diagram of plan construction detail

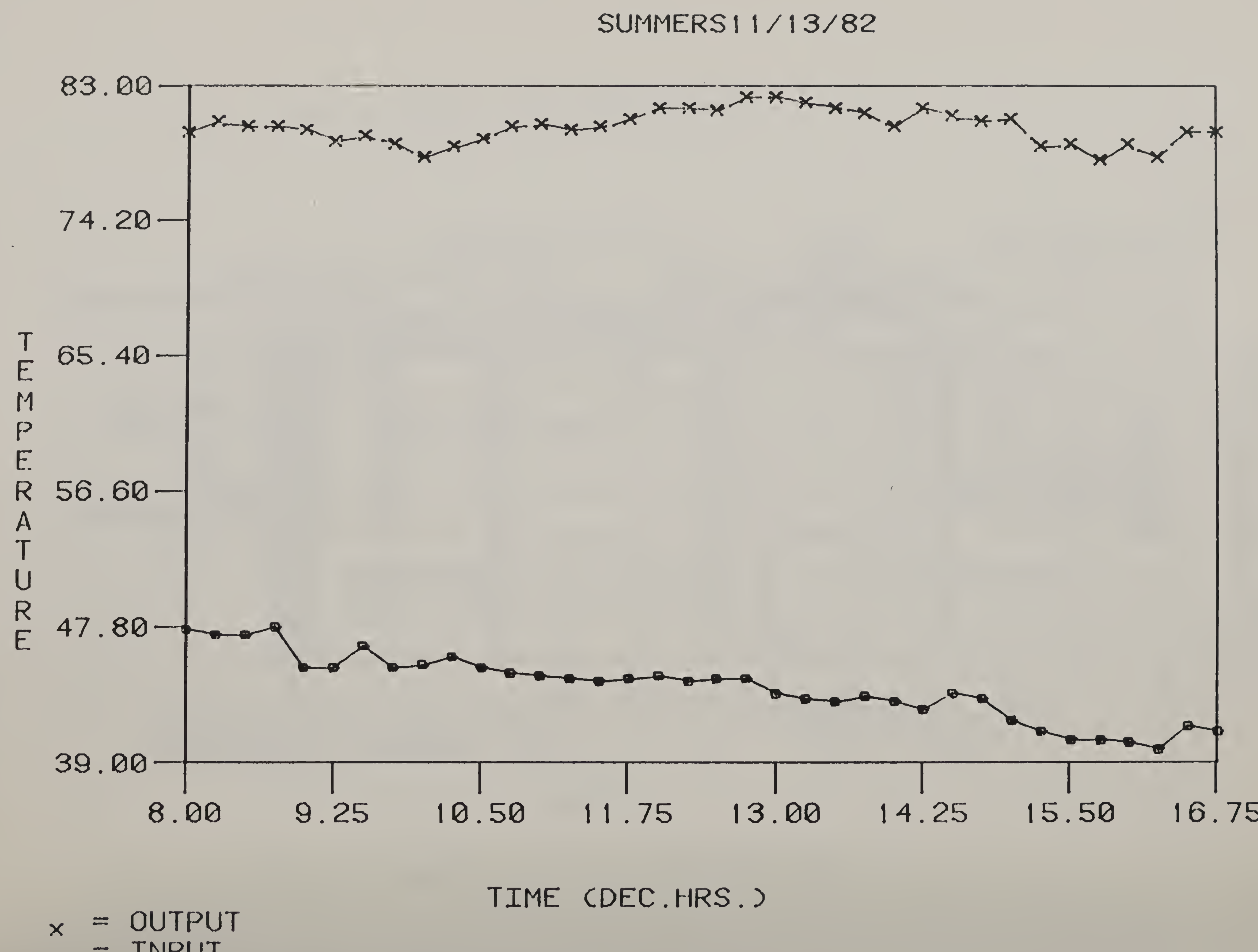

Figure 3. Typical performance data for system.

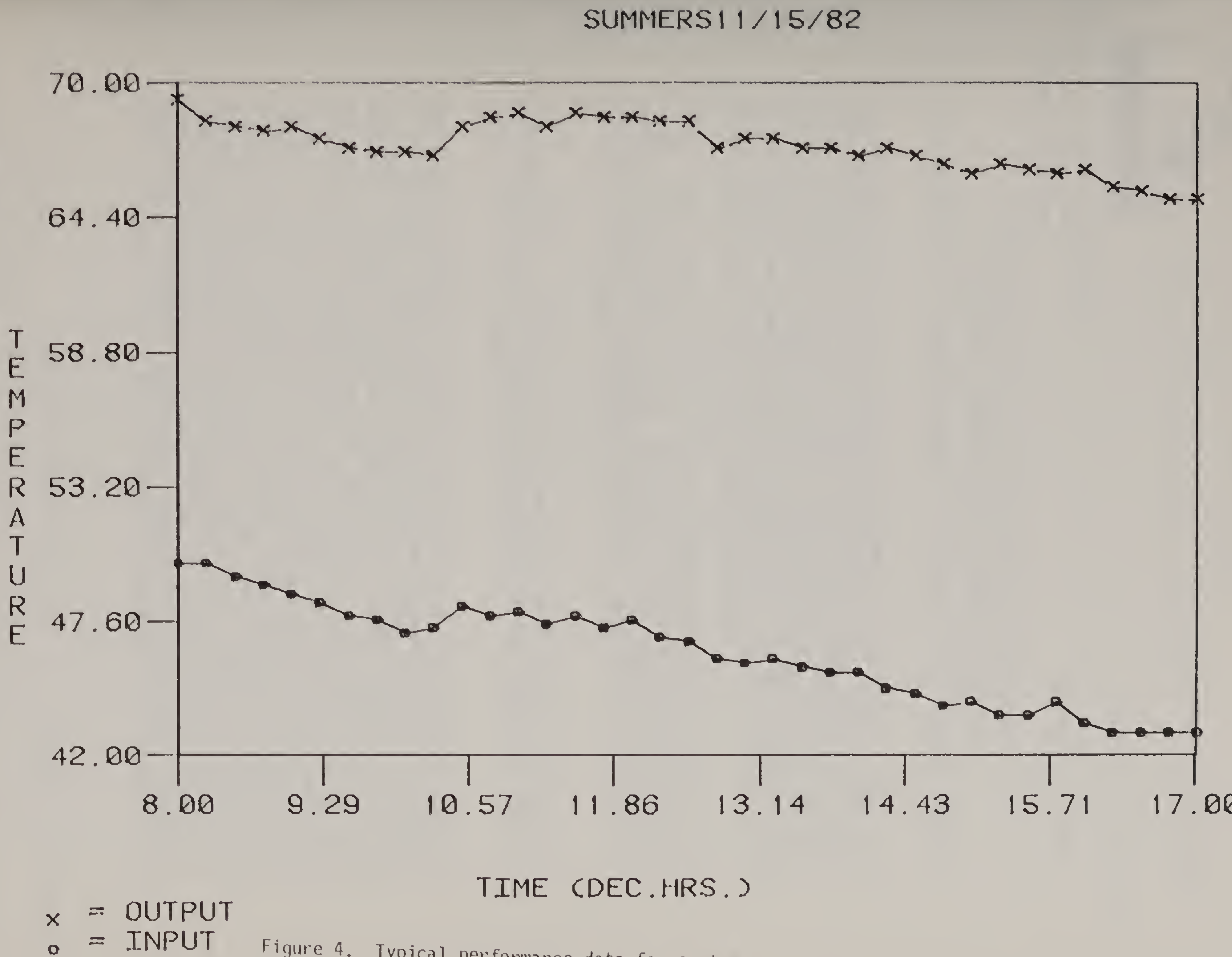

Figure 4. Typical performance data for system.

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December 30, 1982

DeSoto County Land and Cattle Company Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, ~~P.E., Project Leader~~; M. K. Elfino, ~~P.E., Project Engineer~~

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: The DeSoto County Land and Cattle Company is managed by Clive Morris and is located 16 miles southeast of Arcadia, FL, east of State Road 31 (approximate latitude 27°N).

DESCRIPTION OF FARM: The DeSoto County Land and Cattle Company consists of 24,000 acres that actually fall in three counties; DeSoto, Charlotte, and Highlands. The acreage utilization is 6,000 acres of intensively managed (irrigated) muckland, 8,000 acres of improved pasture, with the remainder natural range land and pine timber. The 4,000 acres of corn are harvested in June and July. This corn is harvested as high moisture corn (30% w.b. at harvest). Some is stored in bunker silos and ag-bag systems. Much of it is sold to area beef and dairy operations as high moisture corn. The corn is followed by a second crop of sorghum, both grain and silage, planted on 3,500 acres, and harvested in October and November. Sod grass is worked on 1,000 acres. Alfalfa is grown on 100 acres and Bahia grass is also harvested for seed. The base cattle herd consists of 2,000 head but other heifers on a backgrounding growing program range from 6,000-12,000 head. There are no grain drying or storage facilities available. A need exists to dry some grain for livestock and

poultry feed as well as to dry grass seed. Mr. Morris has some experience with solar energy for crop drying in another part of the world.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar hot-air system to provide all the heat for shallow-bed grain and seed drying.

2. To test the specialized dryer (shallow-bed wooden bin) designed for total solar drying of grains and seeds under the higher temperatures and humidities in the southeast.

SOLAR SYSTEM DESIGN: An E-W oriented 20 x 220 ft free-standing equipment shed was available for construction of a bare-plate collector. Panel material was added to the bottom of the prefabricated wooden truss, forming an enclosed attic 150 ft long beneath the metal roof. A shallow-bed dryer (approximately 16 x 20 ft) was constructed in the west-most equipment bay. A fan (12,000 cfm) was connected to the plenum beneath the shallow-bed dryer. A duct constructed of 2 x 4 material and exterior plywood carries air from the west end of the attic down to the fan entrance dog house. The fan pulls air into the enclosed attic on the east end of the building, through the 3,000 ft^2 collector, down the duct, through the dog house, and finally into the shallow-bed dryer plenum and through the 2 to 4 feet of material to be dried (approximately 1,000 bushels of corn). Figures 1 and 2 show construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was $4,000 for an average cost of $1.35/$ft^2$ of collector surface.

PERFORMANCE: The solar drying system at the DeSota County Land and Cattle Company location is complete and has been operational tested. Only limited performance data has been collected at present but the performance appears to conform to design performance criteria.

During testing in October 1982, the average solar radiation at the collector location was 1,220 BTU/day based on an 8 hour day. The total radiation for the 3,000 ft^2 collector was 3.66 x 10^6 BTU/day. The air flow through the system was 6,000 cfm. The average temperature rise was 8°F. The average relative humidity during the test period was 85%. The average energy gained by the heated air was 0.415 x 10^6 BTU/day, resulting in an efficiency of 11%. The equivalent heating provided by L.P. gas would require 4.6 gallons and based on a cost of $1.00 per gallon, the amount of savings was $4.60/day. The drying season for corn, grass seed, and other crops grown is estimated to be 200 days per year. A simple cost analysis indicates a payback period of 4-1/2 years.

Figures 3 and 4 show typical performance data. Additional data collection is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: DeSoto County Land and Cattle Company personnel constructed the solar collector and shallow bed drying bin and the construction quality was very good. The only significant problem encountered was excessive noise produced by the drying fan. It appears that this fan noise is a result of excessive frictional pressure drop between the enclosed attic and the fan inlet. To correct this problem, plans to construct a gradual transition in the enclosed attic for smoother air flow at the exit are under consideration. Insulation of the connecting duct is also under consideration to reduce noise and energy loss. Noise isolation pads will also be used. The enclosed attic could be sealed better to reduce infiltration and increase the temperature rise. A final approach to increase the temperature rise that is being considered is to paint the exterior galvanized roof flat black which should improve solar energy collection.

The DeSoto County Land and Cattle Company management is generally pleased with their system and are looking forward to using it to dry corn and grass seed during the coming year. This demonstration is a good example of how bare-plate solar collection systems can be installed through roof retrofit of standard trusses type equipment sheds. Also the shallow bed dryer is a good example of a bin for use with solar energy crop drying. No major design changes other than those mentioned above are planned, but further data collection and analysis will be studied for possible system operation and design improvements.

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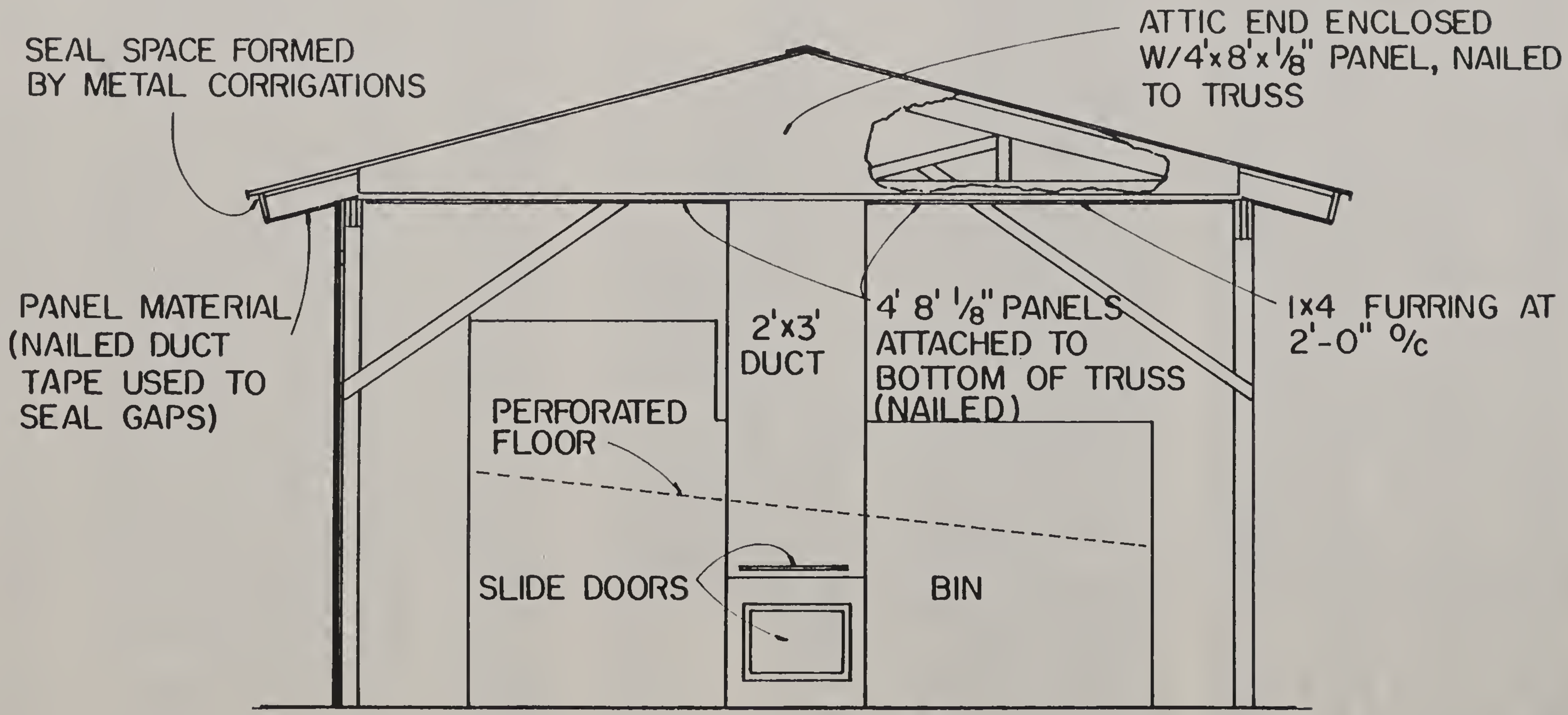

Figure 1. Diagram of cross-sectional construction detail.

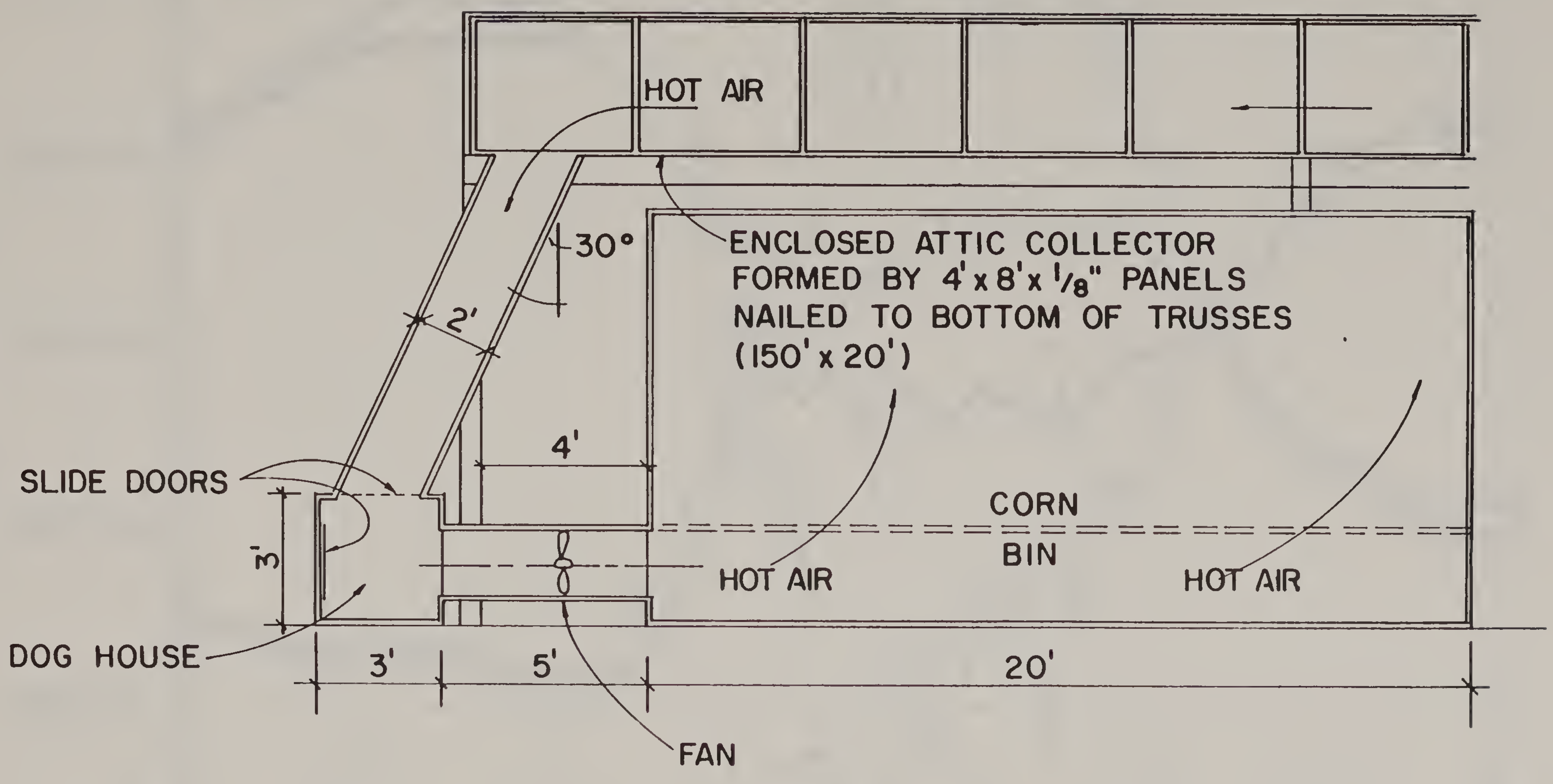

Figure 2. Diagram of air flow through the system.

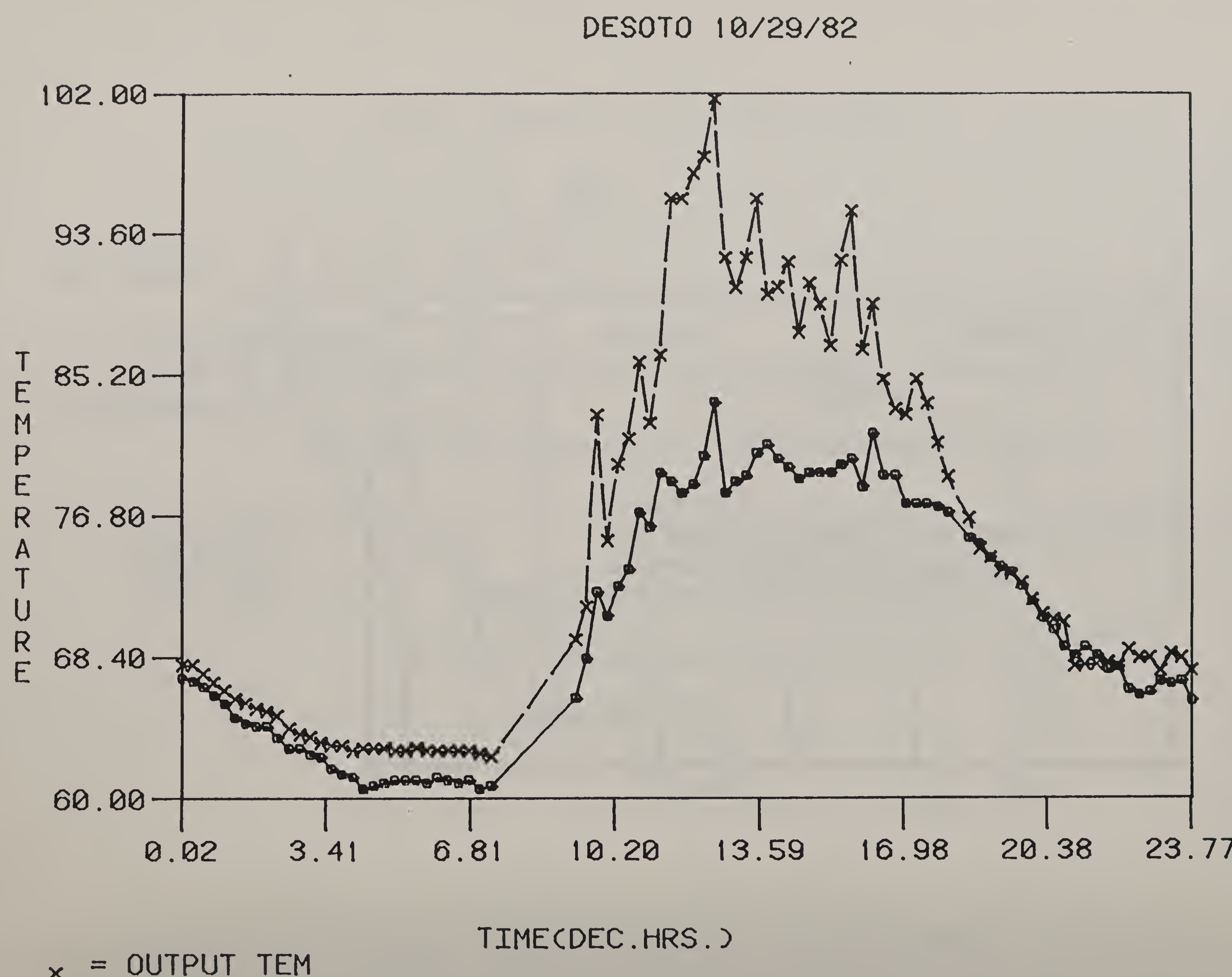

Figure 3. Typical performance data for system.

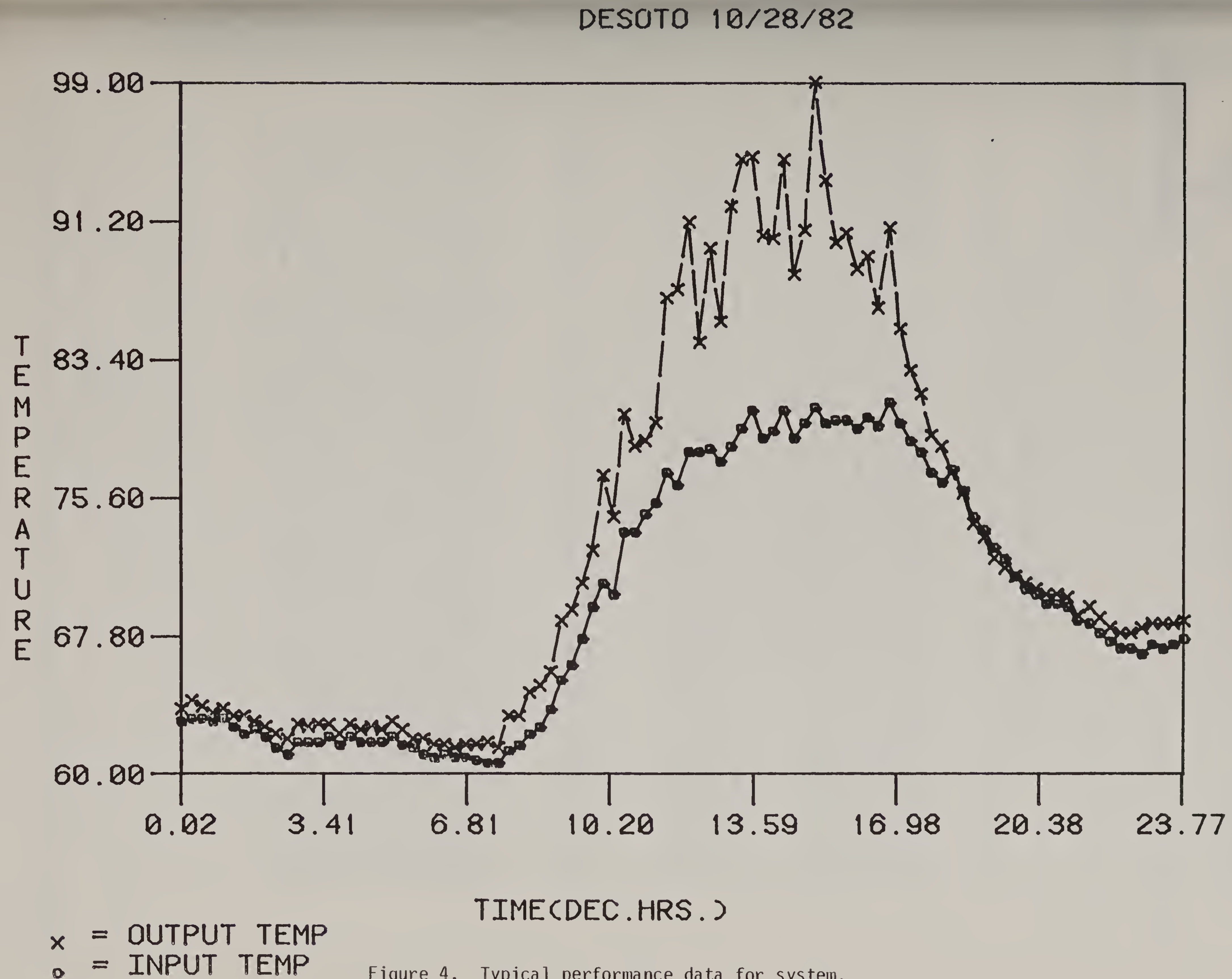

Figure 4. Typical performance data for system.

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December 30, 1982

John Creel and James Lee (C & L) Farm Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, ~~P.E., Project Leader~~; M. K. Elfino, P.E., Project Engineer

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: John Creel and James Lee farm land is located north of Milton, Florida, 5 miles west of Allentown, Florida (approximate latitude 31°N).

DESCRIPTION OF FARM: Mr. Creel and Mr. Lee farm 290 acres of corn, 350 acres of soybeans, 175 acres of oats and sorghum. They also raise hogs and run the C & L Farm Supply Store. The grain drying facilities include two portable high speed dryers and two 4,000 bushel grain bins equipped with a small aeration fan. In the past the high speed dryers have more than paid for themselves, but increasing fuel costs have forced Mr. Creel to shift his drying practice. The high speed dryers will be used very little. Possibly for early corn, on very wet mornings or as an emergency backup. Mr. Creel plans to field dry his corn to 17-18% w.b., then bring the corn down to 14-15% w.b. using aeration. Approximately 600 bushels is loaded per layer, the fréquency of loading varies. No record of last year's drying cost is available.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar system to supplement a low temperature grain drying operation.

2. To determine the efficiency of collecting solar energy with a plastic hot-air collector used as a supplemental heater and establish the percent of drying energy available from this source.

3. To dry shelled corn from 18% w.b. to 14.5% w.b. using a solar supplemented aeration system.

SOLAR SYSTEM DESIGN: The collector selected is basically a plastic flat-plate collector. The size is 20 by 100 ft (2,000 ft^2) and it is oriented in the E-W direction. A wood frame (2 x 4 pressure treated lumber) provides the main structure for the collector. The collector is covered with 6-mil clear plastic (polyethylene, glazing material) and the floor is covered with 6-mil black polyethylene (absorber material). Between the black polyethylene and the clear plastic, there is a layer of shade cloth (black polypropylene) with 47% opening. The shade cloth is supported by a plastic tube which is placed in the middle of the collector and runs the entire length of the collector. The plastic tube will be inflated during operation to prevent the shade cloth from touching the black polyethylene. The air is delivered at the inlet end of the collector by an inflation fan (10,080 cfm, 0.5" s.p., 2 HP) to keep the collector inflated. Between outlet of the collector and the drying bin, there is a duct and a transition box with adjustable gates for controlling air flow. Figures 1 and 2 show construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was $4,000 for an average cost of $2.00/ft^2 of collector surface.

PERFORMANCE: The solar drying system on the Creel and Lee farm was completed but major damage occurred during operational testing. Santa Rosa County Extension personnel constructed the solar collector with assistance from University of Florida personnel. The construction quality was inadequate. The collector was lifted by the inflation fan, pulling the hold down stakes from the ground and causing the frame to break in several locations. Extensive damage to the clear plastic cover also occurred. The collector failure was due primarily to poor construction techniques rather than the construction design plans although the inflation fan appears to have been over designed. Materials have been purchased and the system will be reconstructed with minor design modification before the next drying season.

No performance data could be collected but the performance of a similar solar drying system at another demonstration location provides a good estimate of the expected performance of this system, which should have an efficiency of 45%. The average solar radiation at the Creel and Lee farm during corn drying season (June-August) is estimated to be 1,500 BTU/hour

based on an 8 hour day. For the 2,000 ft^2 collector, the total radiation would be 3.00 x 10^6 BTU/day. The average temperature rise is estimated as 15°F with a system air flow rate of 10,000 cfm. This would result in an average energy gain by the heated air of 1.35 x 10^6 BTU/day. The equivalent heating provided by L.P. gas would require 15 gallons and based on a cost of $1.00 per gallon the amount of saving would be $15.00/day. For a drying season of 30 days (neglecting any use drying soybeans, oats, or for pig house heating), a simple cost analysis indicates a payback period of 8 years.

Figure 3 shows typical performance data of a similar type system. Additional data collection is planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: The problem of the collector lifting off the ground when inflated will be solved with improved hold down post and inflation fan inlet design and proper construction techniques. The construction crew did not install the wood anchor post to a depth as specified in the construction plans. To correct this problem, holes will be dug at each post location and a tee will be attached to the base of the post to produce a deadman effect when the holes are filled and compacted. The proper size nails will also be used to construct the frame and attach the post to the frame. A box will be constructed around the fan inlet so that an adjustable curtain can be installed to this fan inlet box to partially block the inlet in order to reduce the uplift after the collector is fully inflated.

The collector will be reconstructed and additional data collection and analysis will be studied for possible system operation ad design improvements.

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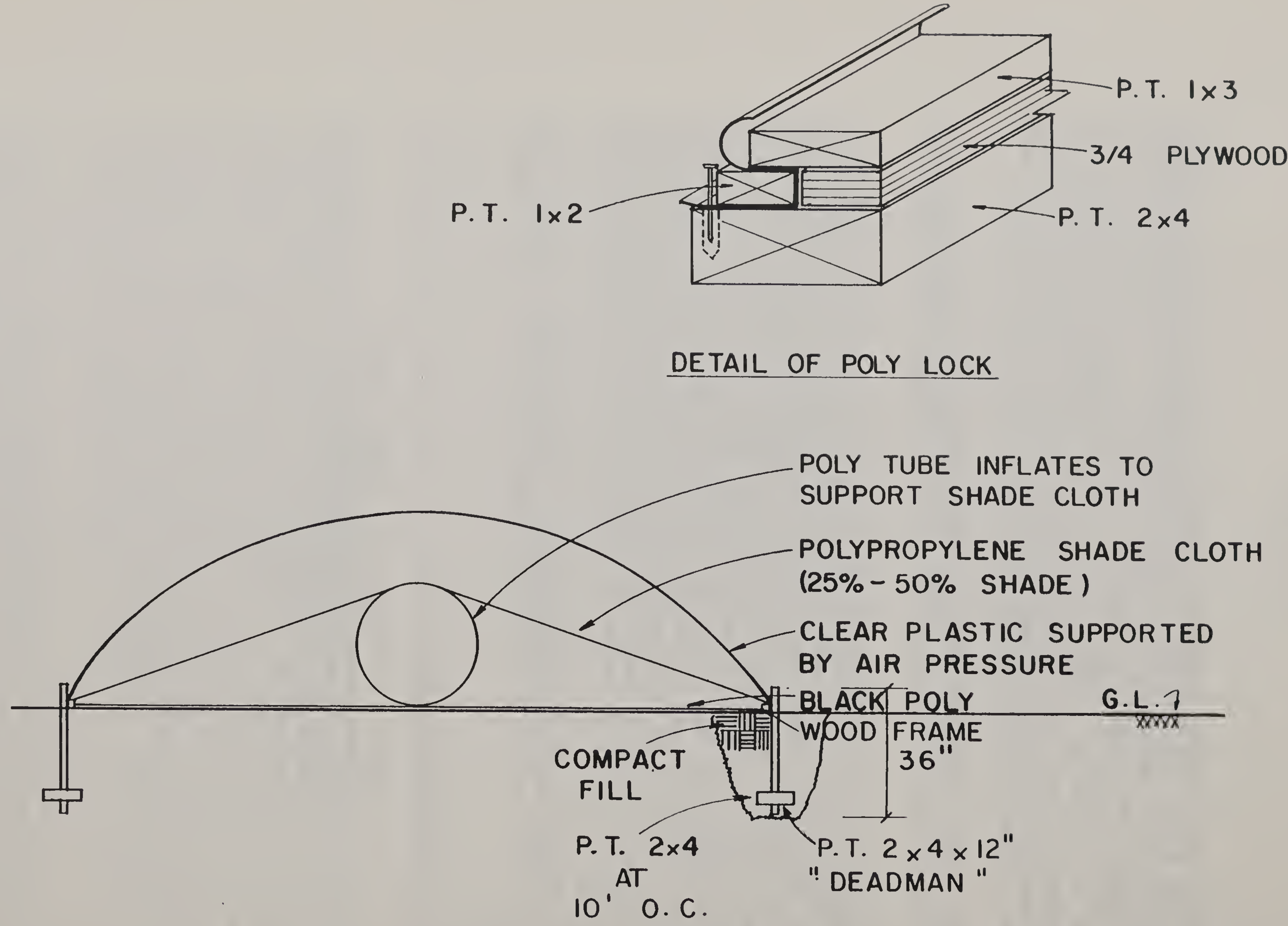

Figure 1. Diagram of cross-sectional construction detail.

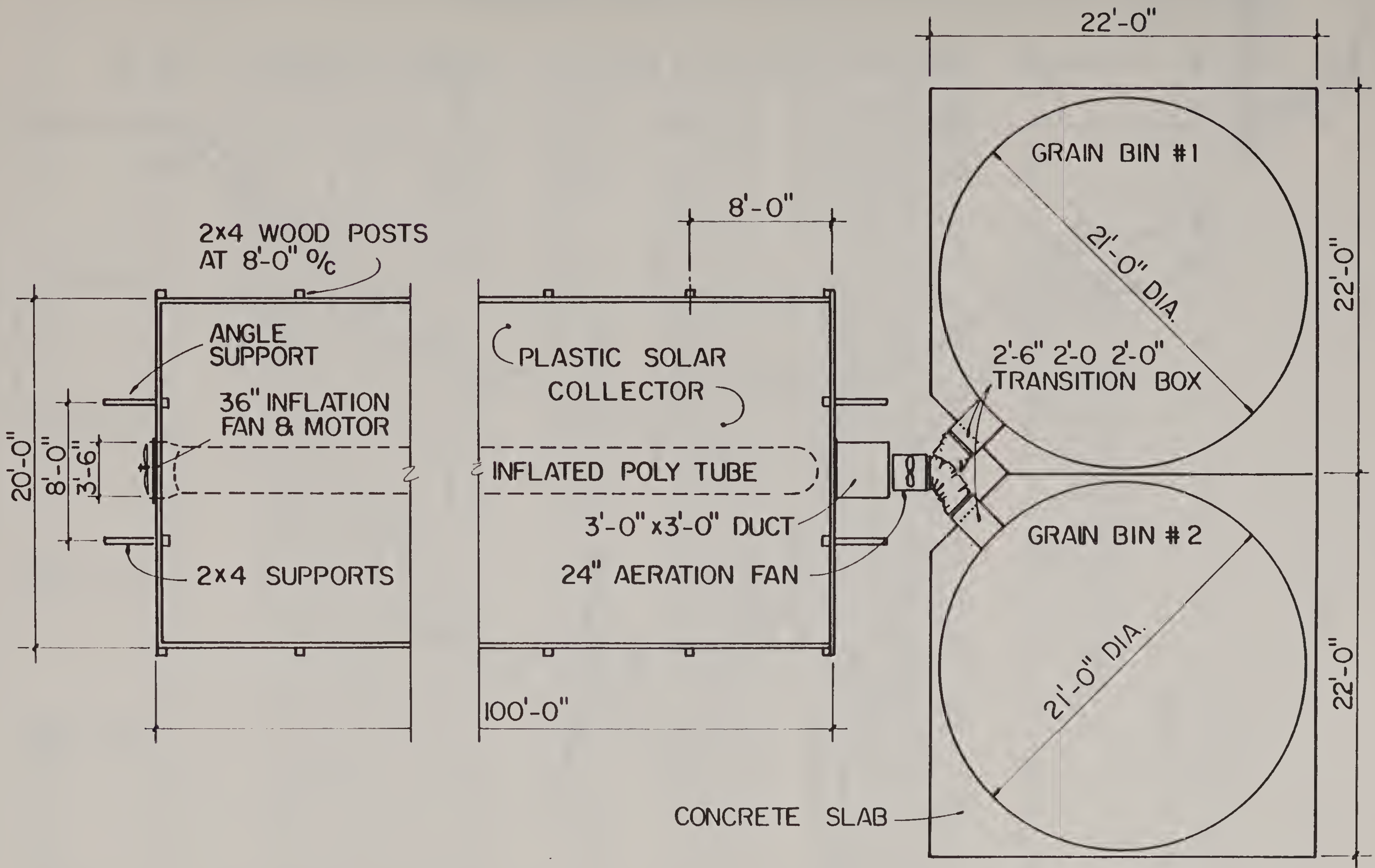

Figure 2. Diagram of plan construction detail.

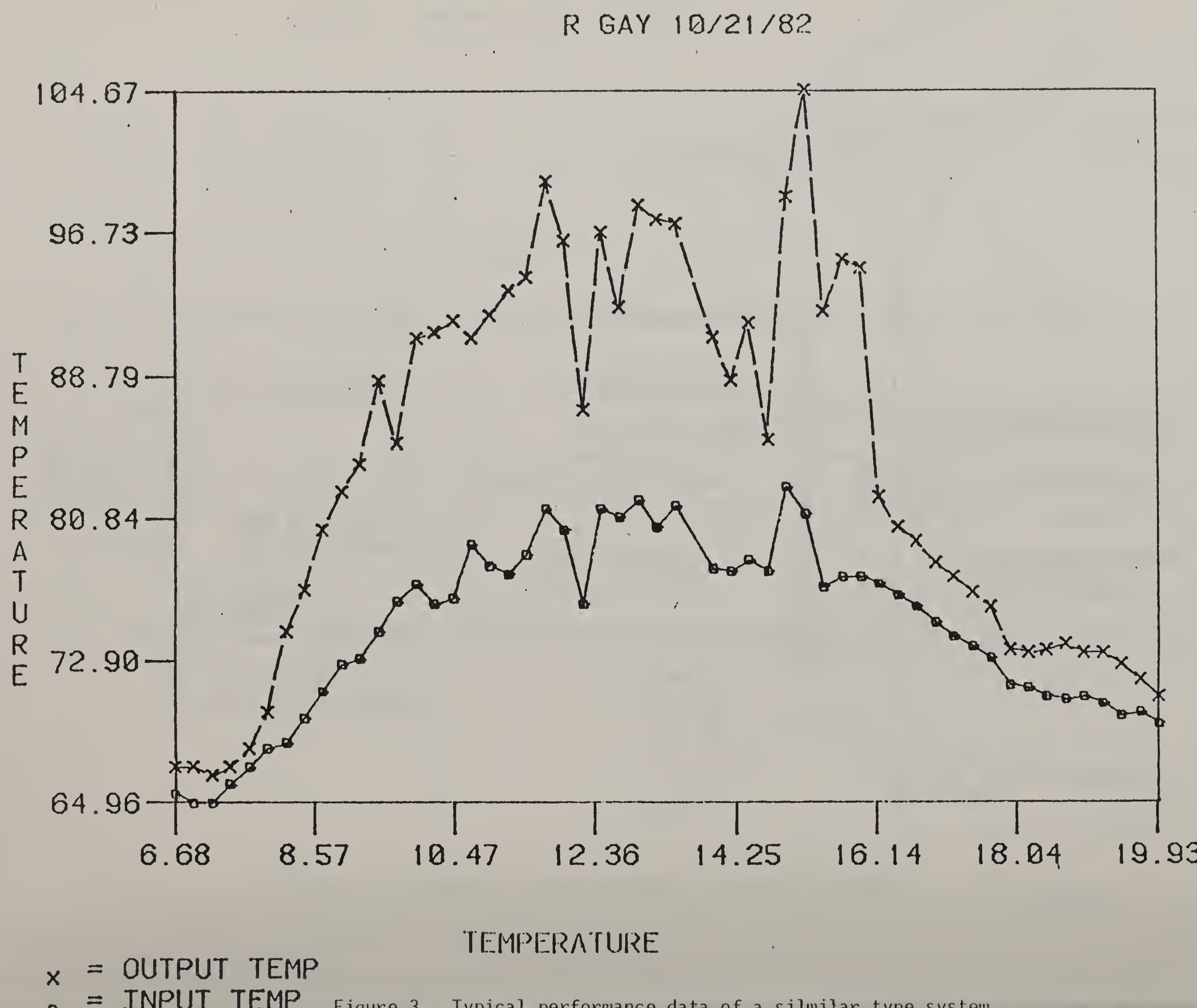

Figure 3. Typical performance data of a silmilar type system.

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December 30, 1982

Gerald Boeckner Farm Demonstration
On-Farm Solar Demonstration of Crops and Grains

M. T. Talbot, ~~P.E., Project Leader~~; M. K. Elfino, ~~P.E., Project Engineer~~

INTRODUCTION: The United States Department of Agriculture (USDA) with pass-through funds from the United States Department of Energy (DOE) provided funding for ten pilot projects of on-farm demonstrations of solar drying of crops and grains in each of nine states. Florida was selected for participation in this program, and awarded $106,000 funding to establish on-the-farm demonstrations in cooperation with ten Florida crop and grain farmers. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

This project summary of one of the ten demonstrations was prepared as a final report for submission to USDA. This publication describes the cooperators facilities, project objectives, solar drying system design, cost and economics, performance, and provides commentary on construction, operation, and suggests modification.

FARM LOCATION: The Gerald Boeckner farm is located north of Pensacola, FL, in Escambia County, east of State Road 99, near Walnut Hill, FL (approximate latitude 31°N).

DESCRIPTION OF FARM: Mr. Boeckner farms 135 acres of corn, 200 acres of wheat followed by 200 acres of soybeans on his 382 acre farm. All his grain is sold and he uses his drying and storage facilities to aid his marketing. The drying facilities are modern and consist of two 7,500 bushel grain bins with double auger stirrers, a 10-14 HP fan/L.P. heater and a 2.5 HP suction aeration fan. The corn is harvested in June-July at 25% (wb) and dried to 15% (wb). Loading rate varies as does size of loads. Mr. Boeckner estimates he used approximately 110 gallons of fuel year before last to dry 6,500 bushels of corn (only one bin was installed) using heating and aeration. A 48 by 60 ft pole barn equipment shed is adjacent to the grain bins.

GOALS AND OBJECTIVES: The following objectives governed the design of this system:

1. To test the concept of a solar pre-heat system to reduce fuel consumption during conventional grain drying.

2. To evaluate a conventional solar heated air configuration with regard to collector efficiency and percent drying load available from solar.

3. To provide spacing heating of equipment shed or farm house in winter.

SOLAR SYSTEM DESIGN: The N-S oriented 40 x 60 ft equipment shed was used to construct a bare-plate collector, forming 20 air channels by attaching paneling beneath the wooden purlins. The purlin formed air channels run N-S. Air enters the air channels beneath the south end of the shed and is heated as it passes underneath the metal roof (2,400 ft^2 of collector area). The warm air leaves the purlin air channels and is collected in a triangular shaped collection plenum. The warm air passes from this attic plenum through the north wall and is ducted down the outside of the north wall. This drop duct is connected to a rectangular duct which is connected to the drying fan inlet with a custom made fabric duct.

To provide additional heat, a free-standing portable collector will also be used. The size of the collector is 12 ft x 12 ft in the form of a covered-plate collector. The design is very similar to that of Purdue University (AE-108 'Solar Heat for Grain Drying').

The collector tilt is 30° for the location, which is at latitude 31°. The air inlets from the top into 6 channels and it is sucked through using a 16" diameter fan which is rated at 1,975 cfm at 0.25" s.p., 1/4 HP. The back of the collector is a triangular shape plenum with the fan mounted to one side. A flexible duct 16" diameter will be used to connect to the dog house where the drying fan is located. This system is designed as a pre-heater for grain drying and space heating where it could be moved near by the space where heat is needed. Figures 1, 2 and 3 show construction detail.

CONSTRUCTION COST: The total cost (materials and labor) for this system was \$2,000 for an average cost of \$0.83/ft^2 of collector surface. For the portable collector cost of materials only is \$400, for an average cost of \$2.78/ft^2 of collector surface.

PERFORMANCE: The bare-plate solar drying system on the Boeckner farm is complete and was used to dry wheat, corn, and soybeans last drying season. The portable collector has not been constructed. Mr. Boeckner anticipated a higher temperature rise but analysis of the limited performance data collected at present indicates the performance conform to design performance criteria for this bare-plate collector.

During testing in November 1982, the solar radiation available during a very cloudy testing period was 700 BTU/ft^2 based on an 8 hour day. The

total radiation for the 2,400 ft^2 collector surface was 1.68×10^6 BTU/day. The average flow through the system was 4,000 cfm. The average temperature rise was 6°F. The average relative humidity during the test period was 80% while the daytime ambient temperature was 65°F. The average energy gained by the heated air was 0.207×10^6 BTU/day, resulting in an efficiency of 12%. The equivalent heating provided by L.P. gas would require 2.3 gallons and based on a cost of $1.00 per gallon, the amount of savings was $2.30/day. For an estimated drying season of 120 days, a simple cost analysis indicates a payback period of just over 7 years.

Figure 4 shows limited performance data. Additional data collection is necessary and planned during the next drying season and analysis of this data will provide further performance evaluation.

COMMENTARY: Mr. Boeckner and his son constructed the bare-plate collector and the construction quality was very good. The major construction problem resulted from inadequate sealing of adjacent 4 x 8 sheets of 1/4 inch thermoply boards. Tape was used on half these joints, but a switch to overlapping sheets for the last half of construction provided a much better seal. Retaping and stapling the tape over the unlapped joints should eliminate most of the leakage.

The data available is not a true indication of possible system performance. Monitoring equipment problems forced a testing period after the drying season and the weather was poor during the testing period. The fan used during the testing was smaller than normally used by Mr. Boeckner during drying. The grain bins were full of properly conditioned soybeans and to avoid any problems, the air from the collector was not forced through the bins during testing. Mr. Boeckner monitored the temperature rise with a digital thermometer during the drying season and reported a 4-9°F temperature rise. To help increase this temperature rise, painting the metal shed roof flat black will be considered.

Mr. Boeckner plans to complete the portable collector during the winter. No major design changes are planned but, further data collection and analysis will be studied for possible system operation and design improvements.

For more information contact:

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Extension Agricultural Engineer
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University of Florida
Gainesville, FL 32611

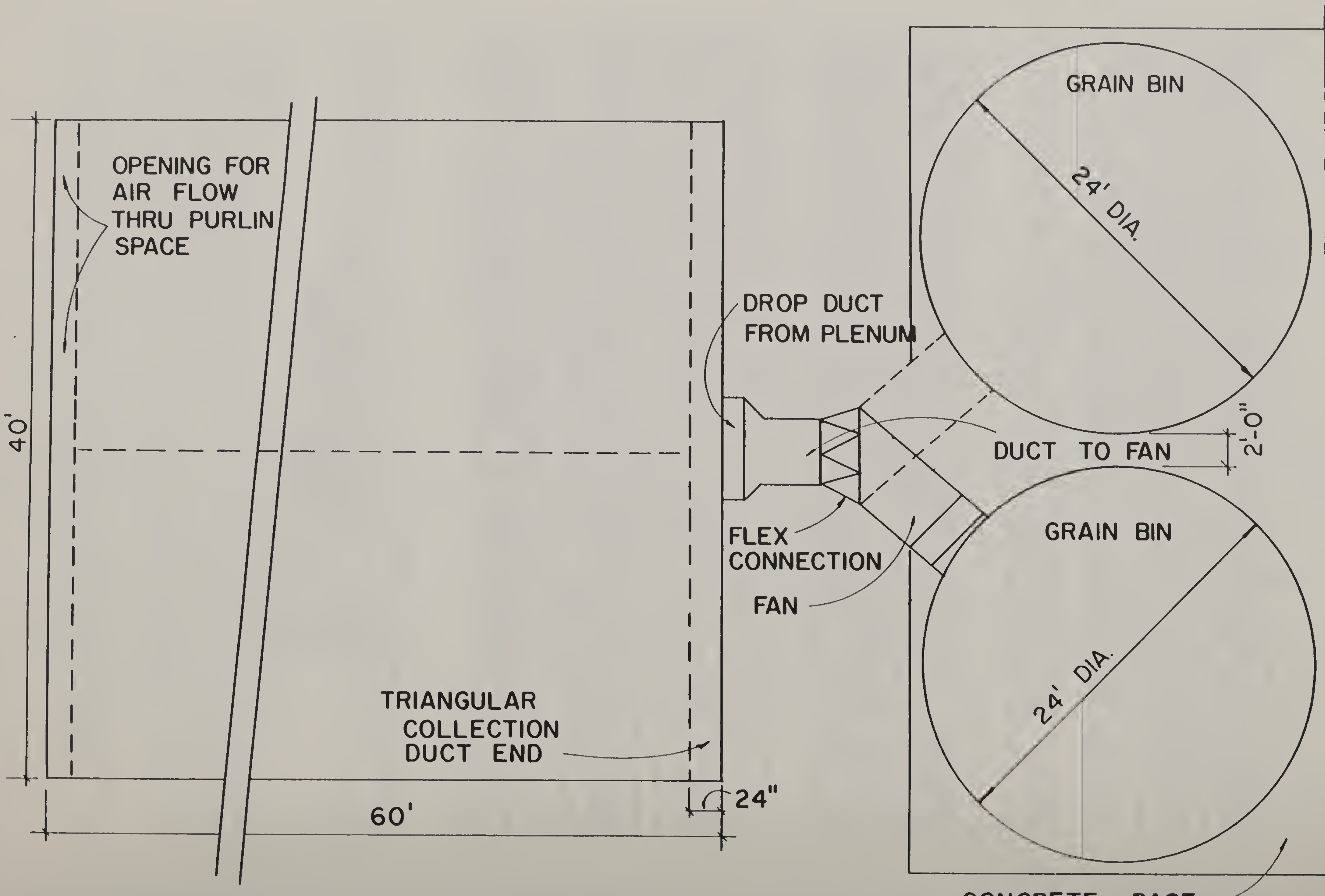

Figure 1. Diagram of plan construction detail of system.

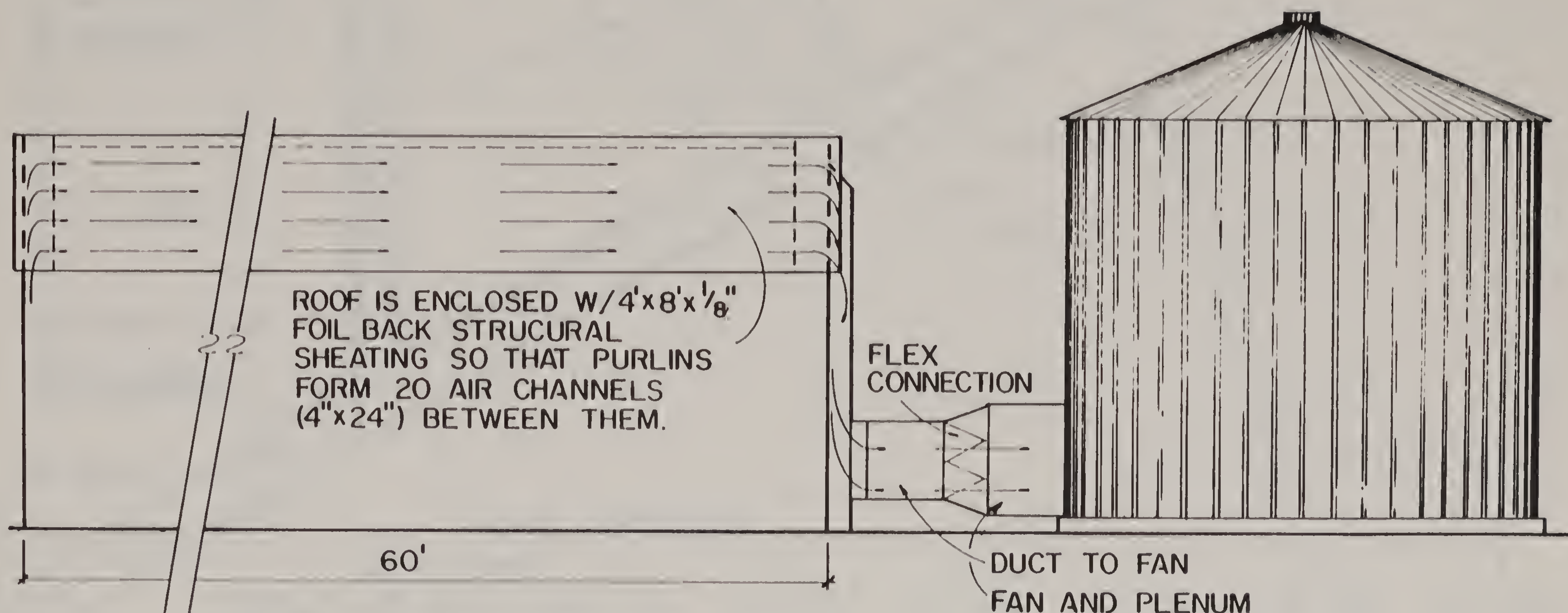

Figure 2. Diagram of air flow through system.

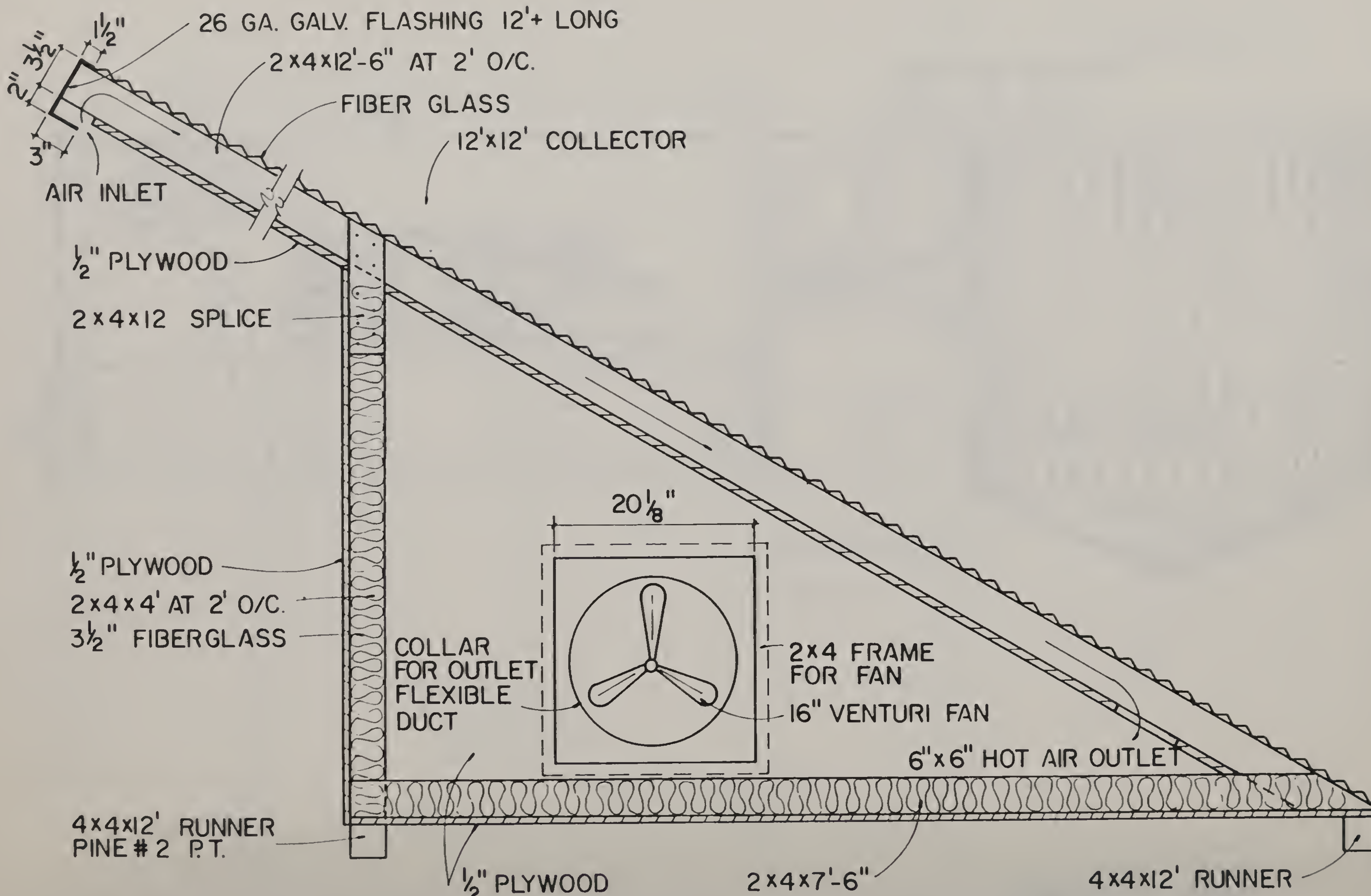

Figure 3. Diagram of cross-section constructional detail of portable collector.

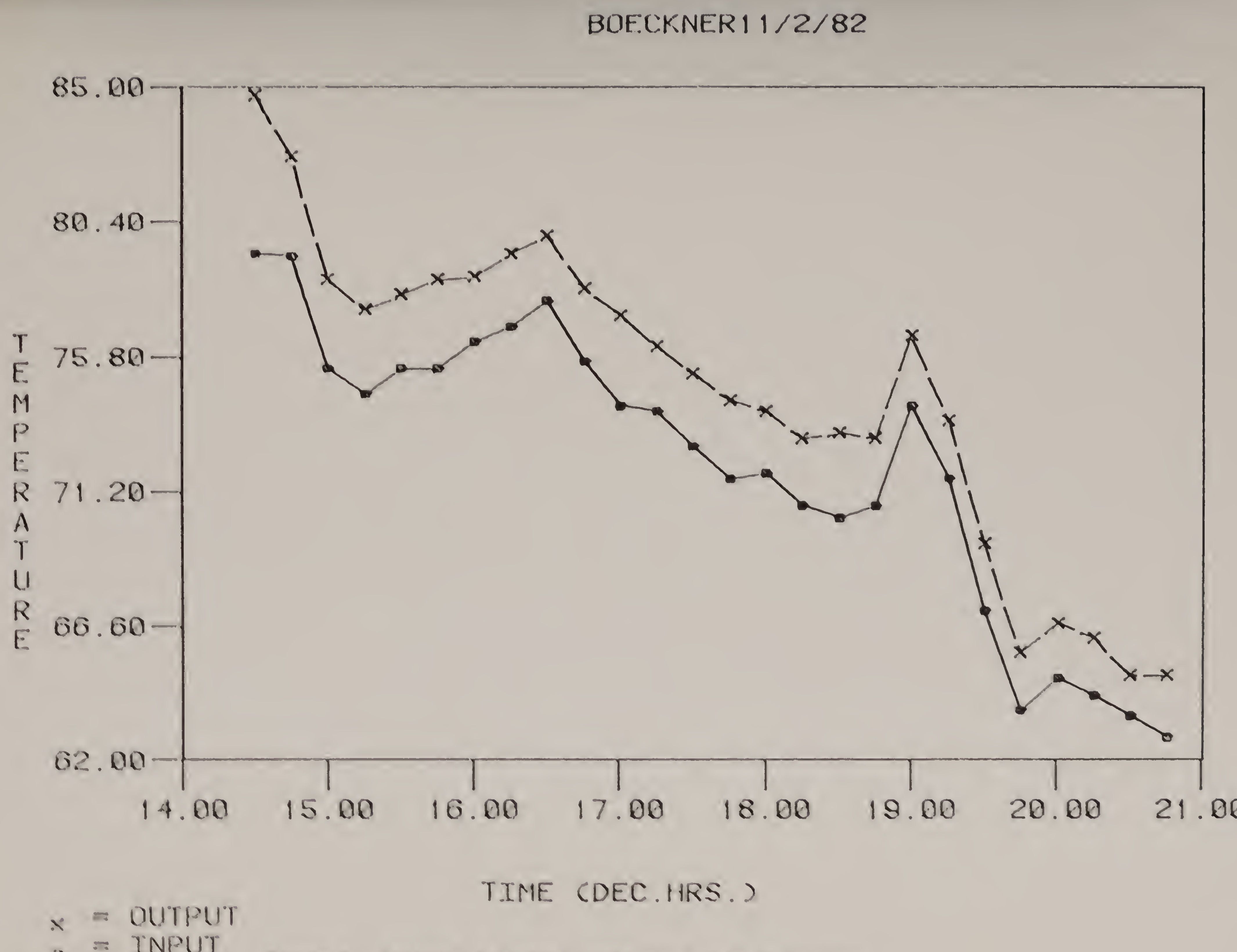

Figure 4. Diagram of limited performance data for system.

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ON-FARM SOLAR DRYING OF CROPS AND GRAINS

Demonstration Project

Final Report

Sponsored by:

Cooperative Extension Service
University of Illinois, Urbana-Champaign

Department of Agricultural Engineering

In cooperation with:

United States Department of Agriculture
Cooperative Extension Service

and

United States Department of Energy

Cooperating farmers:

Dan Ponder
Steve Funk
Dale Sass
Alfred Guebert
Vernon Vahlkamp
Dale Steffen
Rodney Lindsey

Project Coordinator: David W. Morrison
Project Manager: William H. Peterson

ON-FARM SOLAR DRYING OF CROPS AND GRAINS DEMONSTRATION PROJECT

Project Overview

In January of 1981, the Department of Agricultural Engineering through the Cooperative Extension Service at the University of Illinois signed an agreement with USDA/SEA-Extension to cooperate in a demonstration of on-farm drying of crops and grains, one of nine states participating in this project. Pass-through funds from the U.S. Department of Energy were made available to establish solar systems on operating farms to demonstrate the use of solar energy for drying of crops as well as other uses for the same solar systems that were appropriate to the individual farms. Objectives were:

1. Demonstrate that simple, low-cost solar collectors can provide significant amounts of heat energy for drying of grain and hay.
2. Demonstrate that significant amounts of energy can be saved in comparison with gas or electric heat drying systems.
3. Demonstrate that solar collectors incorporated in the roofs and/or walls of machinery storage buildings and livestock shelters and used primarily for drying grain can also provide energy for heating livestock shelters and farm shops.
4. Demonstrate that a free-standing, moveable solar collector can be used for drying grain during the harvest season and then moved to provide space heating during the winter.
5. Demonstrate that a solar collector attached to a grain drying bin can be used for drying of grain by low-heat methods.
6. Demonstrate that there are situations under which solar drying is competitive in cost with conventional drying practices.

Seven demonstration farms were selected, with two main criteria in mind. One was that each farm offer something unique and different from the others, from which something could be learned, and the other was the systems be distributed as widely as possible around the state to make them accessible for visits by more Illinois farm operators, in spite of the extra travel and time required for monitoring activities. Locations are shown in Figure 1.

All of the cooperators had shown an interest in the use of solar energy prior to selection for participation by actually constructing and using a solar agricultural facility.

Because of prior commitments of personnel, work did not begin until the fall of 1981, when the existing drying systems were monitored. Most of the designs were completed and reviewed in the winter of 1981-82, so that the improvements in uses of solar energy other than drying were not completed for monitoring in the winter of 1981-82. It was anticipated that these would be completed and monitored in the winter of 1982-83, and the report written in the summer of 1983, but the earlier-than-planned termination of the project makes it impossible to include that information in this report.

Monitoring Procedures

Equipment items purchased during this project for monitoring purposes were:

1. Campbell CR5 recorder with millivolt integrator, temperature integrator, temperature sampler, and audio cassette tape interface.
2. LI-COR LI-1776 Solar Monitor
3. Natural Power Delta-T temperature recorder
4. 2-Cole-Palmer single point temperature recorders
5. Aeolian Kinetic 682-RH Btu Monitor
6. 3-running time meters

This equipment, plus other monitoring instruments already available in the Agricultural Engineering Department allowed continuous solar and temperature information to be recorded at each solar demonstration site during the entire crop drying process.

Initial corn moisture levels at each monitored site were obtained by oven-drying samples taken by the cooperator. Final moisture levels were determined by using a vacuum probe sampling system to obtain corn samples from throughout the grain bed depth and then oven-drying these samples.

Grain bin airflows were determined by measuring grain bin plenum static pressures and using the appropriate fan performance data to determine airflow. Airflow in solar collectors was measured with a hot wire anemometer.

At demonstration sites which had seperately metered grain bins, fan energy usage was determined from the electric meter. At those sites which were not metered, fan energy usage was calculated from running time information (assuming a 90% motor efficiency).

Economic Evaluation

Because of the many different possible assumptions as to interest rate, depreciation, inflation, taxes, and other factors involved in solar systems, and because system life can not be known at this time, the economic evaluation is done on the basis of a "simple payback" of investment in years to recover the investment.

No tax credits are included in figuring the cost of systems, though there would have been some in most cases, again because of the variability of such credits with time and location. Initial costs used are those existing at the time when the coopeator built his system.

Fuel costs assumed are 75 cents per gallon of propane and 6 cents per kilowatt-hour of electricity. In each case, the annual savings in both Btu's and the typical fuel source are given so that the future reader can evaluate probable savings in terms of the existing situation.

In some cases savings are estimates, based on limited amounts of monitoring because the cost of intrumenting of every project at all times would have been beyond the available budget. However, we feel that there is a good basis for all of the estimates, because there is data available to use with a knowledge of the individual farmer's operation upon which to base an estimate.

We did not have "control" systems with which to make comparisons as is usual with research projects, but we were able to include several "comparison" systems, using non-solar methods in several instances. Because these were under the same management, using the same kind of corn, as were the compared solar systems, we feel that the comparisons are very useful.

We have used only one approach to economic analysis in each case, but realize that many approaches are possible. It is our intent to provide enough information so that readers can make their own analysis, by their own methods, if they wish.

1. PONDER
2. FUNK
3. SASS
4. GUEBERT
5. VAHLKAMP
6. STEFFEN
7. LINDSEY

Figure 1. Locations of cooperators in the demonstration project.

Educational Activities

Publications

1. Morrison, David W. Illinois Protable Solar Collector. Energy Tips 7, Nov. 1982. Department of Agricultural Engineering, University of Illinois, Urbana, IL.

2. Morrison, David W. Guides for Incorporating Solar Collectors into Agricultural Buildings. Energy Tips No. 8, Nov. 1982, Department of Agricultural Engineering, University of Illinois, Urbana, IL.

3. Morrison, David W. Retrofit Agricultural Solar Collectors. Energy Tips No. 9, Nov. 1982, Department of Agricultural Engineering, University of Illinois, Urbana, IL.

Plans

Portable Solar Collector, No. SP546, Revised 1981. Department of Agricultural Engineering, University of Illinois, Urbana, IL. Over 5000 copies of this plan have been sold, including both original and revised versions.

Tours

Tour of Cooperator Steffen's solar system on July 28, 1982. Attendance: 20.

Visit to Cooperator Sass' solar system by AE 299 class, Spring 1982. Attendance: 50.

Radio

Radio interview of D. Morrison by Tom Jones, Coordinator of Public Information for University of Illinois. Used by approximately 40 stations.

1982 Meetings

Grain conditioning conference, Jan 13-14, 1982, "USDA/DOE Solar Drying Demonstration Program" by David W. Morrison. Attendance, 110.

8 Solar Workshops for Producers -- Total attendance, 250.

4 Farm Builder Solar Workshops -- Total attendance, 145.

1983 Meetings Scheduled

Grain Conditioning Conference, Jan. 26-27, 1983. "Solar Grain Drying Demonstration Program" by David W. Morrison.

14 Producer workshops on Energy Management and Solar Applications, Feb.-March, 1983.

4 Farm Builder Solar Workshops, March 1983.

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COOPERATIVE EXTENSION SERVICE

COLLEGE OF AGRICULTURE
UNIVERSITY OF ILLINOIS AT URBANA - CHAMPAIGN

A WRAP-AROUND SOLAR COLLECTOR ON A DRYING BIN

DAN PONDER
Tuscola, Illinois

Demonstration Project
On-Farm Solar Drying of Crops and Grains

7000-bushel low-temperature drying bin with wrap-around solar collector

A WRAP-AROUND SOLAR COLLECTOR ON A DRYING BIN

THE FARM

The Dan Ponder farm located in east-central Illinois consists of 900 acres of corn and soybeans. Approximately 36,000 bushels of corn are dried on-farm each year in six low temperature drying bins.

GOALS

The main objective of this project was to demonstrate that a wrap-around solar collector mounted on the surface of a grain bin can significantly lower drying costs when compared to a low temperature electric heat grain drying bin.

THE SOLAR SYSTEM

The wrap-around solar collector was built on the southern two-thirds of a 27 ft. diameter grain drying bin. The collector was formed by first painting the southern two-thirds of the grain bin surface black. The blackened metal bin wall served as the solar absorbing surface for the covered plate collector. Next, a collector cover material of clear corrugated fiberglass was suspended around the painted portion of the bin using a series of laminated 1 in. by 2 in. boards. The 3 in. space between the bin wall and the fiberglass cover provided the air channel for the solar collector. The fiberglass cover also partially enclosed the 10 h.p. fan on the bin, thus a portion of the air entering the bin was first solar heated by passing through the collector created by the bin wall and the fiberglass (See Figure 1).

SOLAR SYSTEM COST

Construction cost for the wrap-around solar collector was $1300.

SYSTEM PERFORMANCE

The Ponder solar grain drying system was monitored both in 1981 and 1982. In 1981, the drying performance of the bin equipped with the wrap-around solar collector was compared to the performance of a 27 ft. diameter bin equipped with a 10 hp drying fan and 5.0 kW electric heater. In 1982, the performance of the solar bin was compared with a 30 ft. diameter bin equipped with a 10 hp. fan only. The results of these comparisons are summarized in Table 1.

During 1981, the solar drying bin operated from October 29 to November 28 removing 5.9 percentage points of moisture from 7330 bushels of corn. During this period 10.0 x 10^6 Btu of heat energy was collected by the solar system (an energy equivalent of 110 gallons

of LP gas). During 1982, the solar drying bin operated from October 13 to November 16 removing 4.4 percentage points of moisture from 7560 bushels of corn. During this period 11.1 x 10^6 Btu of heat energy was collected by the solar system (an energy equivalent of 122 gallons of LP gas). Table 2 shows the typical sunny day performance of the wrap-around solar collector.

Table 1. Solar Drying vs. Low Temperature Drying on the Ponder Farm.

	1981		1982	
	Solar Bin	Electric Heat Bin	Solar Bin	No Heat Bin
Fill Date	10/29	10/30	10/13	10/14
Bushels Dried (bu)	7330	7790	7560	8760
Airflow (cfm/bu)	1.24	1.29	1.23	1.05
Initial Moisture (%)	20.8	25.6	20.0	19.0
Final Moisture (%)	14.9	19.4	15.6	15.2
Electrical Usage:				
Fan (kWh)	6050	9600	6800	6600
Heater (kWh)	--	2640	--	0
Total (kWh)	6050	12240	6800	6600
Drying Efficiency (kWh/bu-point moisture)	0.14	0.25	0.20	0.20

Table 2. Sunny Day Collector Performance (Ponder Solar Collector).

Time	Temperature Rise °F	Energy Collected (Btu/hr)
7:00 a.m.	0.0	0
8:00	1.0	9,900
9:00	4.0	39,700
10:00	6.0	59,600
11:00	8.0	79,500
12:00	8.0	79,500
1:00	8.0	79,500
2:00	6.0	59,600
3:00	5.0	49,700
4:00	3.0	29,800
5:00	3.0	29,800
	Total	516,600

Airflow - 9200 cfm
Total Energy Collected - 516,600 Btu
Solar Energy Available - 1,222,800 Btu
Collector Efficiency - 42%

ECONOMIC EVALUATION

During the two drying seasons monitored, the Ponder solar collector collected an average of 10.6 x 10^6 Btu per year of heat

energy. The economic value of this energy was evaluated in the following three ways:

1) Collected solar energy replaces 75¢ per gallon LP-gas heat.
   Dollars saved per year = $87
   Simple Payback Period = 14.9 years
2) Collected solar energy replaces 6¢ per kWh electric heat.
   Dollars saved per year = $186
   Simple Payback Period = 7.0 years
3) Cost of drying corn in solar bin vs. cost of drying same corn in check bins.

   1981: 7330 bushel of corn dried from 20.8% to 14.9% moisture
   Solar bin drying efficiency = 0.14 kWh/bushel/point moisture
   Solar bin drying cost (6¢/kWh) = $363

   Electric heat bin drying efficiency = 0.25 kWh/bushel/point moisture
   Electric heat bin drying cost = $649

   Savings per year = $286
   Simple payback period = 4.5 years

   1982: 7560 bushel of corn dried from 20.0% to 15.6% moisture content
   Solar bin drying efficiency = 0.20 kWh/bushel/point of moisture
   Solar bin drying cost (6¢/kWh) = $399

   No heat bin drying efficiency = 0.20 kWh/bushel/point of moisture
   No heat bin drying cost (6¢/kWh) = $399

   Savings per year = $0
   Simple payback period = (No Payback)

COMMENTARY

During the two years of operation, the wrap-around solar collector operated satisfactorily with almost no maintenance required on the collector. During the 1981 drying season, the solar system used 44% less electrical energy to remove a given amount of moisture from corn compared to the electric heat drying bin. However, this savings is somewhat exaggerated because higher initial moisture content corn in the electric heat check bin caused drying in that bin to extend into late December, a period of adverse drying conditions.

For the 1982 drying season, the solar bin and the no heat check bin both operated at the same drying efficiency levels indicating no apparent saving from the solar system. But, the solar bin was operating at a higher airflow rate per bushel than the no heat check bin. This higher airflow rate per bushel required more fan energy per bushel to dry corn in the solar bin than in the no heat bin, thus

cancelling some of the energy benefit of the solar collector. Also, 1982 was an excellent year for natural air drying, diminishing the solar advantage.

One added benefit found from using the wrap-around collector on the bin was a nighttime temperature rise created by pulling cool night air over the surface of the warmer grain bin. Temperature rises ranging from 1°F to 3°F were measured almost every night during the drying period.

Illinois Solar Plan No. SP546 gives information for constructing a wrap-around solar collector on a round grain drying bin.

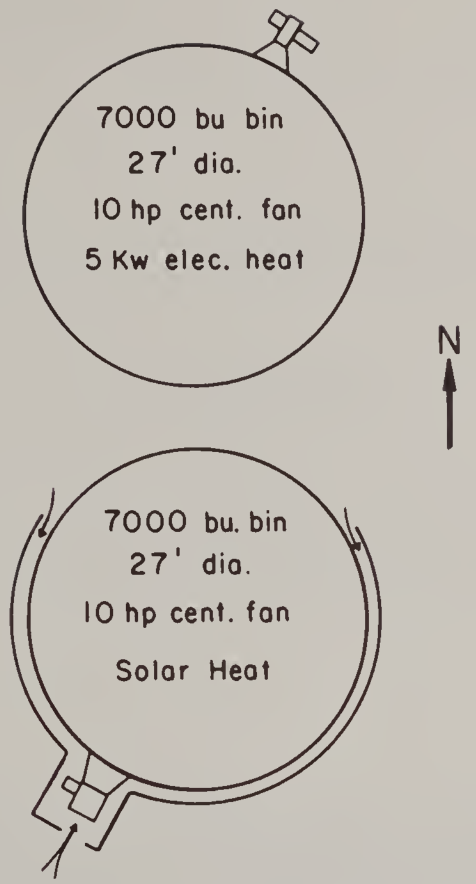


Figure 1. Layout of solar and conventional low-temperature drying bins on the Ponder farm.

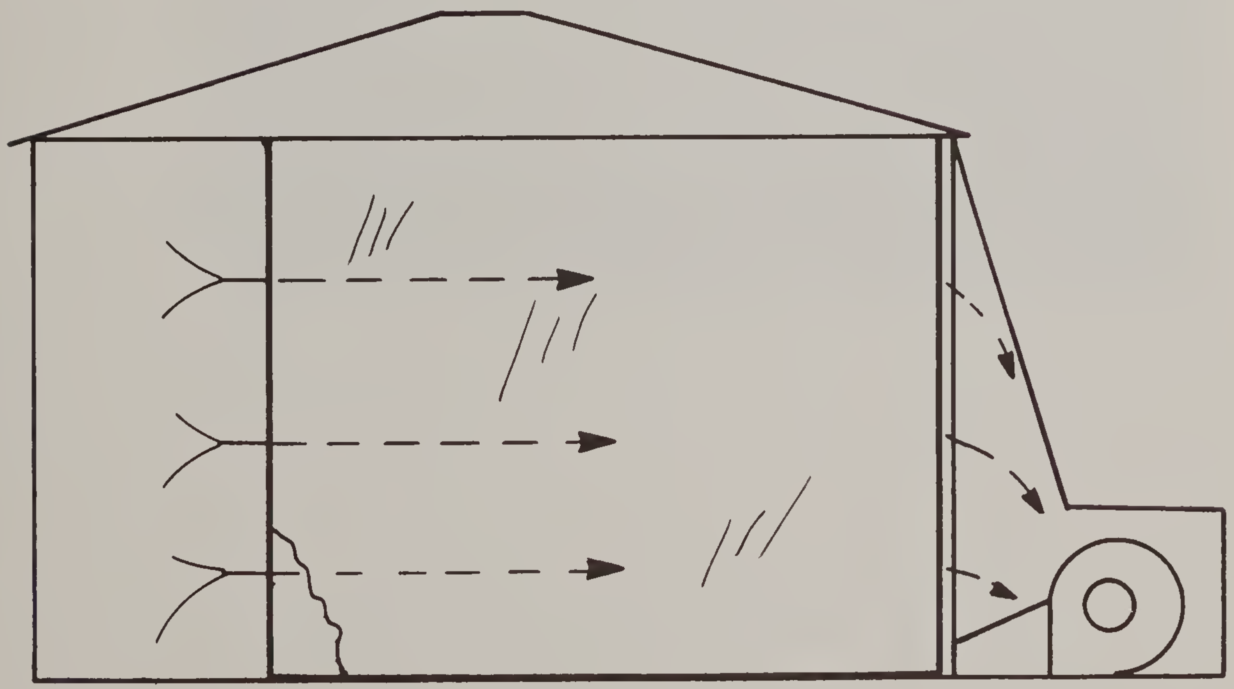


Figure 2. Airflows in solar collector on Ponder bin.

(Ponder Farm)

COOPERATIVE EXTENSION SERVICE

COLLEGE OF AGRICULTURE
UNIVERSITY OF ILLINOIS AT URBANA - CHAMPAIGN

A PORTABLE SOLAR COLLECTOR FOR DRYING AND HOME HEATING

Steve Funk
Shirley, Illinois

Demonstration Project
On-Farm Drying of Crops and Grains

Portable solar collector, designed for crop drying and space heating.

A PORTABLE SOLAR COLLECTOR FOR DRYING AND HOME HEATING

THE FARM

The Steve Funk farm located in central Illinois consists of 218 acres of corn and 218 acres of soybeans. Corn is dried and stored in four 3,300 bushel grain bins located on one farmstead and an 11,000 bushel bin located on a second farmstead.

GOALS

The main objective of this project was to demonstrate that a moveable solar collector can be used to significantly lower grain drying costs in the fall and then be moved and used for a secondary purpose during the winter (crawlspace heating of the farm home).

THE SOLAR SYSTEM

The moveable solar collector constructed on the Funk farm was a 12 ft. high, 24 ft. long unit built using Illinois Solar Plan No. SP546. The 288 ft^2 collector has a 60° tilt angle and is mounted on wooden skids so that it can be moved and used for various heating purposes. The collector is a suspended plate unit designed to be used in two modes, the grain drying mode and the building heating mode. In the grain drying mode, a hinged door at the top of the collector is opened, and ambient air is drawn by the grain drying fan over both sides of the suspended metal absorber sheet. In the building heating mode, the hinged door is closed and inside air from the heated building is drawn into the collector through an insulated duct in the collector back. The air travels only behind the suspended absorber plate and then exits the collector through a second duct in the collector back.

The Funk drying operation already extensively used solar grain drying methods. A wrap-around covered plate collector had previously been constructed on one 3,300 bushel bin and a wrap-around bare plate collector already existed on a second 3,300 bushel bin. The moveable solar collector was used for providing heat for drying corn in the third 3,300 bushel bin, and the fourth 3,300 bushel bin was used as a check bin, using unheated air drying only. All four bins were equipped with 5.0 hp vane-axial fans, so a good drying comparison could be made between the moveable solar collector, the wrap-around collectors, and the no-heat grain bin.

During the winter months the collector is moved to the farm home and is used for crawlspace heating. Air is drawn from the crawlspace, heated by the collector, and then returned to the crawlspace through insulated ducts.

SOLAR SYSTEM COST

The material costs for the moveable solar collector was $1,280. In addition, a blower and differential thermostat cost $170 making the total cost for the system, including controls $1,450.

SOLAR SYSTEM PERFORMANCE

The Funk solar grain drying system was monitored both in 1981 and in 1982. The drying performance of the grain bin equipped with the moveable solar collector was compared to the performance of the two bins equipped with wrap-around solar collectors and also with the performance of the no heat bin. The drying results of these comparisons are summarized in Table 1 and Table 2.

Table 1. Solar Drying vs. No Heat Drying on the Funk Farm (1981)

	Wrap-Around Bare Plate Solar Bin	Wrap-Around Covered Plate Solar Bin	Moveable Collector Solar Bin	No-Heat Bin
Collector Area (ft^2)	2,290	2,290	288	-
Drying Airflow (cfm/bu)	2.1	2.0	2.1	1.9
Fill Date	10/17	10/19	10/20	10/22
Initial Corn Moisture (%)	20.7	20.7	20.3	22.1
Final Corn Moisture (%)	14.1	14.1	14.4	15.8
Bushels Dried (bu)	3,050	3,260	3,050	3,650
Electrical Usage (kWh)	2,680	2,670	2,580	3,080
Drying Efficiency (kWh/bu-point moisture removed)	0.13	0.13	0.14	0.16

Table 2. Solar Drying vs. No Heat Drying of the Funk Farm (1982)

	Wrap-Around Bare Plate Solar Bin	Wrap-Around Covered Plate Solar Bin	Moveable[1/] Collector Solar Bin	No-Heat Bin
Collector Area (ft^2)	2,290	2,290	288	-
Drying Airflow (cfm/bu)	2.0	2.2	1.8	1.7
Fill Date	10/12	10/13	10/14	10/15
Initial Corn Moisture (%)	19.3	20.1	21.3	20.8
Final Corn Moisture (%)	14.9	15.1	16.0	16.3
Bushels Dried (bu)	2,990	2,850	2,540	3,260
Electrical Usage (kWh)	2,780	2,680	2,030	3,280
Drying Efficiency (kWh/bu-point moisture removed)	0.21	0.19	0.15	0.22

1/A 3.0 hp fan was used on the Moveable Collector Solar Bin in 1982 because of fan failure.

During 1981, the grain drying period for the drying bin equipped with the moveable solar collector ran from October 20 to November 15. During this period, 8.51×10^6 Btu of heat energy was collected by the solar system (an energy equivalent of 93 gallons of LP gas). In 1982, a 3.0 hp. fan had to be used on the bin equipped with a moveable collector because of fan failure. The bin operated from October 14 to November 17. During this period, 6.54×10^6 Btu of heat energy was collected for an energy equivalent of 71 gallons of LP gas. Table 3 shows the sunny day collector performance of the moveable collector for drying grain.

Table 3. Sunny Day Collector Performance (Sass Solar Collector)

Time	Temperature Rise (°F)	Energy Collected (Btu/hr)
8:00	0.7	4,900
9:00	7.2	50,500
10:00	7.9	55,500
11:00	9.4	66,000
12:00	7.2	50,500
1:00	6.8	47,700
2:00	6.1	42,800
3:00	6.8	47,700
4:00	3.2	22,500
	Total -	387,100 Btu

Collector Airflow - 6,500 cfm
Total Energy Collected - 387,100 Btu
Solar Energy Available - 543,500 Btu
Collector Efficiency - 71%

The moveable collector was monitored for the crawlspace heating of the Funk home from mid-March to mid-April, 1982. A running time meter was placed on the fuel oil furnace in the home to record furnace operation and degree day data was recorded for the entire monitoring period. For the first nine days of monitoring, the collector was not operated so that a base heating load on the house could be established. During this period, the furnace operated 0.138 hours for each degree day. For the remaining 24 days of the monitoring period the collector was operated. During this period the furnace operated 0.108 hours per each degree day, a decrease of almost 22%. Over this 24 day time span the collector supplied 1.7×10^6 Btu of heat to the crawlspace.

ECONOMIC EVALUATION

During the two years of monitoring, the moveable solar collector collected an average of 7.53×10^6 Btu per year of heat energy during grain drying or an energy equivalent of 82 gallons of LP-gas. Assuming that the collector also reduces fuel oil consumption for home heating during the winter by the same reduction found during the monitoring

period (20 percent), 135 gallons of fuel oil could also be saved. The payback for the collector with such saving would be:

Dollars saved:	82 gallons of LP @ $.75/gallon =	$ 61
	135 gallons of Fuel Oil @ $1.05/gallon =	142
	Total per year =	$203

Simple Payback: $1,450/$203 = 7.14 years

COMMENTARY

The moveable collector proved to be a good heat source for the size of grain bin used (3,300 bushel). On larger drying bins equipped with larger fans, more than one solar unit would be needed if solar energy was to provide significant amounts of heat energy for drying.

Although the collector is described as a movable unit, it is somewhat cumbersome to move because of its size. A unit that is to be moved over any distance or moved frequently should be constructed with a better method for movement than the wooden skid arrangement shown in Illinois Solar Plan No. SP546.

Finally, more wintertime crawlspace heating data is needed on the moveable collector. Monitoring that was performed in 1982 occurred in late winter and early spring when ambient conditions were milder. Data is also needed during the colder mid-winter period to determine the overall effect of using the moveable collector for crawlspace heating.

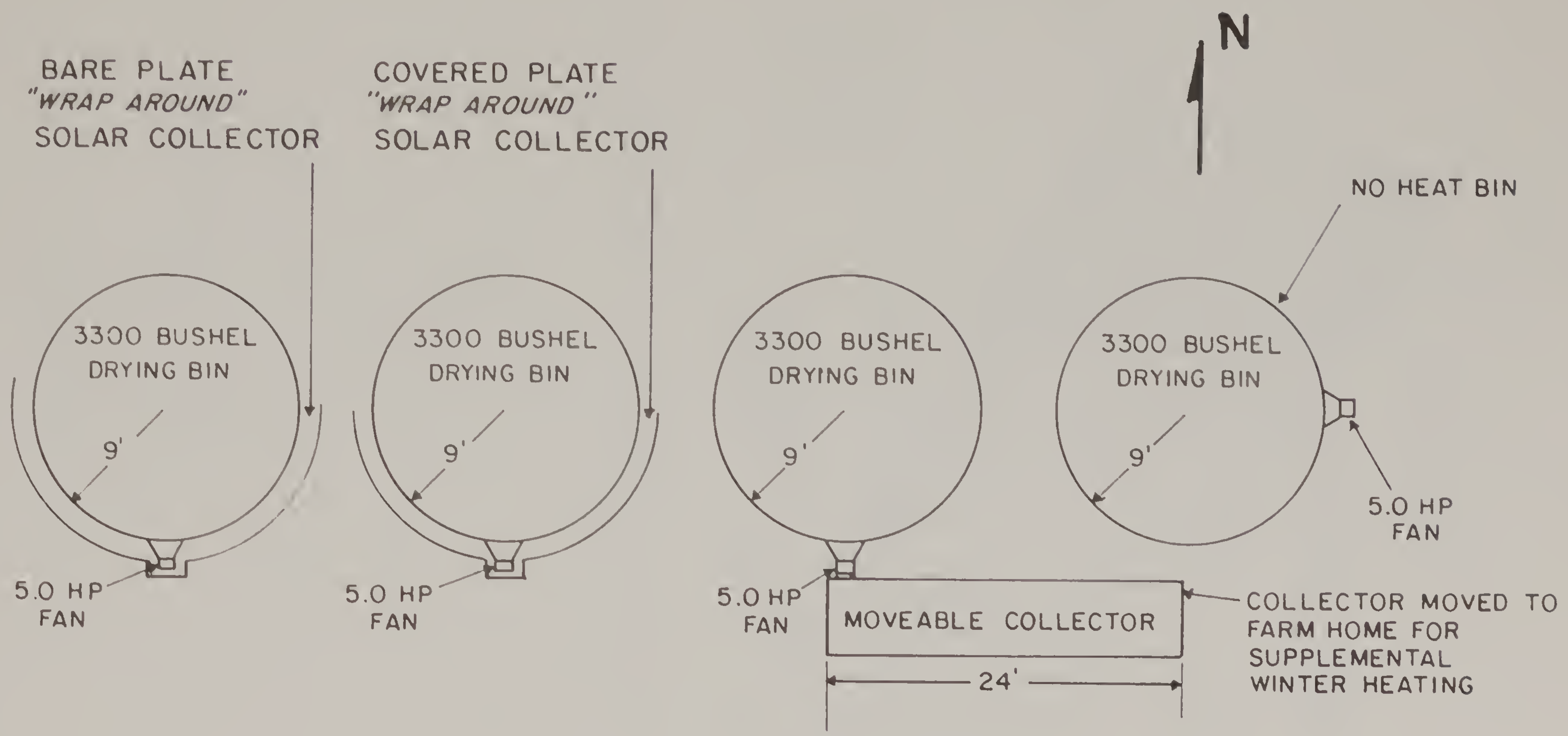


Figure 1. Plan view of drying bins used on the Funk farm.

(Funk Farm)

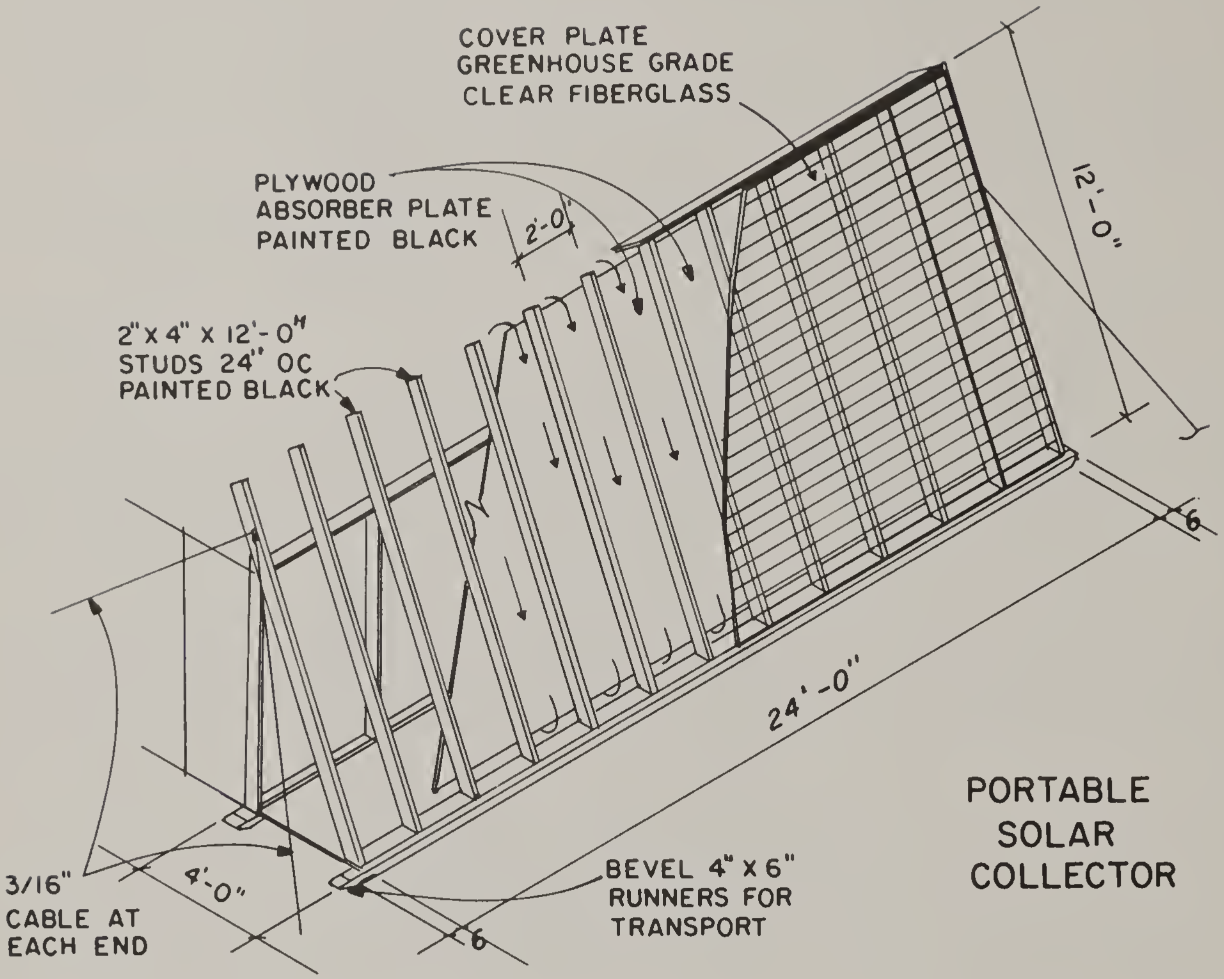


Figure 2. Basic portable solar collector as designed for crop drying on the Funk farm.

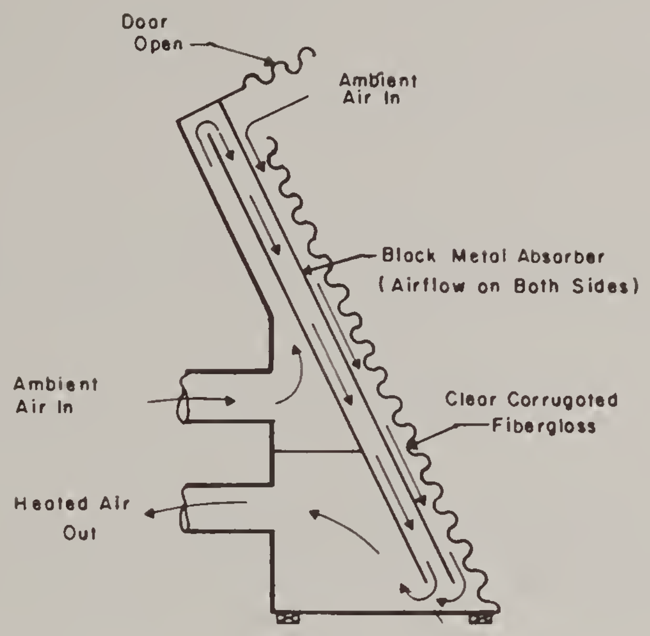


Figure 3. Airflows in the portable solar collector as used in the grain drying mode on the Funk farm.

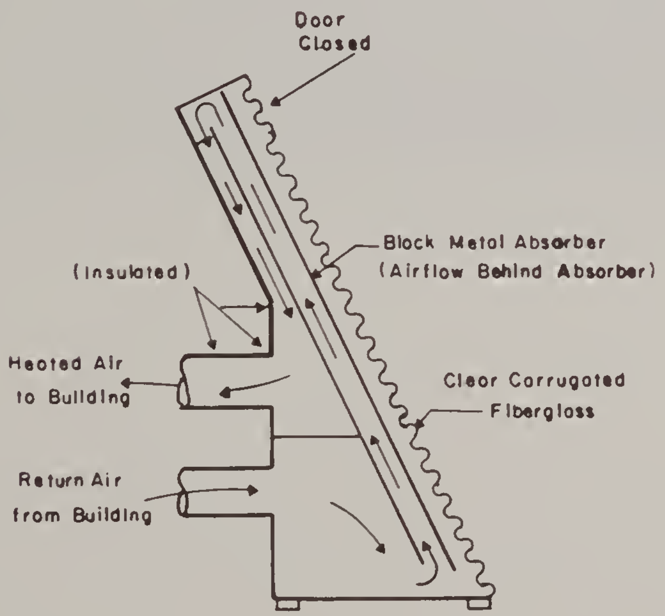


Figure 4. Airflows in the portable solar collector as used in the space heating mode on the Funk farm.

(Funk Farm)

COOPERATIVE EXTENSION SERVICE

COLLEGE OF AGRICULTURE
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

A MACHINE SHED WITH SOLAR ATTIC FOR DRYING AND SHOP HEATING

Dale Sass,
Streator, Illinois

Demonstration Project
On-Farm Solar Drying of Crops and Grains

Machine shed with solar attic used for drying and shop heating.

A MACHINE SHED WITH SOLAR ATTIC FOR DRYING AND SHOP HEATING

THE FARM

The Dale Sass farm located in central Illinois consists of 740 tillable acres. Approximately 55,000 bushels of corn are dried on-farm each year; 30,000 bushels in a propane fired batch-in-bin system and 25,000 bushels utilizing solar energy.

GOALS

The primary objective of this demonstration was to compare the energy requirements of the solar drying system with the energy requirements of the propane fired batch-in-bin system. The secondary objective was to improve the performance of the solar system heating a farm shop during the winter months.

THE SOLAR SYSTEM

Solar heat for grain drying was provided by 4700 ft^2 of solar collector built into the roof and south wall of a 52 ft. by 110 ft. pole type machine shed. The roof portion of the solar collector was formed by first attaching 1/8 inch thick black painted Masonite to the lower cords of the roof trusses to create an attic space in the building. Clear, corrugated fiberglass was used as the roofing material on the south half of the roof instead of metal, thus forming an attic solar collector in the building. A covered plate solar collector was incorporated into the south 16 ft. high side wall by using clear corrugated fiberglass as the exterior wall covering attached on the outside of the six inch thick building poles and then constructing a secondary solar absorbing wall of Masonite on the inside of the poles (Figure 1).

During grain drying, air entering the solar collector enters from inside the machine shed into a slot at the bottom of the south wall, travels up the south wall between the fiberglass and Masonite, and then enters the attic space of the building. Air is then drawn out of the attic through a vertical duct and over to two grain bins through an 80 ft. long on-the-ground horizontal duct (Figure 2).

The grain drying system consists of a 30 ft. diameter, 10,000 bushel bin equipped with a 10 hp fan and a 36 ft. diameter, 15,000 bushel bin equipped with a 20 hp fan. Both bins are equipped with stirring devices. As a secondary use, the solar collector was used to heat a farm shop formed by enclosing the west 40 ft. of the building. Solar heated air can either be drawn directly out of the solar attic into the shop area for space heating, or can be directed through a rock heat storage located beneath the shop's concrete floor. The rock heat storage was formed by burying the approximately 1 1/2 ft. of coarse rock beneath the floor of the shop area before the concrete shop floor was poured. Air ducted out of the solar attic is forced through the

rock and then travels up the south solar wall back to the attic area. As the rock storage slowly heats up, the concrete floor also warms, thus floor heat with some storage capability is provided by the rock beneath the concrete floor arrangement.

To improve the efficiency of the solar attic during the winter months, a vertical covered plate solar collector approximately 7 ft. by 40 ft. is being built in the attic over the shop portion of the building (Figure 3). Heated air from the vertical collector will be used for providing higher temperature air for shop heating. To augment the energy falling on this secondary collector, a foil reflector will be placed on the attic floor.

SOLAR SYSTEM COST

The cost of the solar system plus modifications were as follows:

Solar Collector:	$3,080
Added Cost for Shop Heating:	950
Labor:	825
Shop Heating Modifications:	2,000
Total	$6,855

SOLAR SYSTEM PERFORMANCE

The solar grain drying system was monitored both in 1981 and 1982. The solar drying was compared with an LP-gas batch-in-bin drying system also used by the Sass farming operation. Drying results of these two years are summarized in Table 1.

During 1981, the grain drying period for the solar drying system ran from October 2 to November 19. During this period, 5.87×10^7 Btu of heat energy was collected by the solar system (an energy

Table 1. Solar Drying vs. LP-Gas Drying on the Sass Farm

	1981		1982	
	Solar Drying	LP-Gas Drying	Solar Drying	LP-Gas Drying
Bushels Dried (bu)	22,700	35,300	21,500	42,700
Initial Corn Moisture (%)	21.7	21.0	21.0	21.5
Final Corn Moisture (%)	15.2	15.0	15.7	15.5
Electrical Consumption (kWh)	23,200	8,470	14,540	11,170
LP-Gas Consumption (gal.)	--	3,180	--	4,196
Comparative Drying Costs (¢/bu-point of moisture removed)	0.61	1.07	0.53	1.43

1/1981 energy costs on Sass farm: LP-Gas = $0.61/gallon Electricity = $0.0387/kWh
2/1982 energy costs on Sass farm: LP-Gas = $0.76/gallon Electricity = $0.0415/kWh

equivalent of 640 gallons of LP gas). During 1982, the grain drying period ran from September 27 to October 27. During this period 7.32×10^7 Btu of heat energy was collected (an energy equivalent of 800 gallons of LP gas). Table 2 shows the daily collector performance for drying grain on a typical sunny day.

Table 2. Sunny Day Collector Performance, Drying (Sass Solar Collector)

Time	Temperature Rise (°F)	Energy Collected (Btu/hr)
8:00	0	0
9:00	1.5	49,900
10:00	8.0	266,100
11:00	11.0	365,900
12:00	13.0	432,400
1:00	14.0	465,700
2:00	14.0	465,700
3:00	13.0	432,400
4:00	9.0	299,400
5:00	3.5	116,400
6:00	0	0
	Total -	2,893,900 Btu

Collector Airflow - 30,800 cfm
Total Energy Collected - 2,894,000 Btu
Solar Energy Available - 8,003,000 Btu
Collector Efficiency - 36%

The unmodified solar shop heating system was monitored over a 16 day period from late February to early March. During this period, the average ambient temperature was 27.3°F. The average shop temperature over this same time span was 47.9°F indicating that the solar collector-rock heat storage system was maintaining shop temperatures an average 20°F warmer than outside air. During periods of high insolation, the collector could provide solar heated air 60°F warmer than outside air to the shop for space heating. Figure 5 shows the temperature fluctuations in the shop during a four day period of varying solar conditions.

ECONOMIC EVALUATION

Because of the difficulty in estimating the economic value of a heated farm shop, the payback period for the Sass building was calculated for the solar grain drying only. The total cost for materials and labor for the solar drying portion of the system was \$3905. The actual energy cost reduction for drying corn in the solar system compared with what it would have cost to dry the same corn in the Sass LP-Gas drying system averaged \$853 per year less for the two monitoring years. This \$853 per year savings results in a simple payback period of 4.6 years for the solar drying system.

COMMENTARY

The Sass solar drying system performed well during the two years of monitoring with no problems encountered. The stirring device in the solar drying bins proved useful in eliminating any overdrying problems. In 1981, drying costs were 43% less in the solar drying setup than in the LP-Gas drying system. Because of higher LP-gas prices, drying costs were 63% less in the solar drying system in 1982 than in the LP-gas system.

To increase the heat output of the solar collector during grain drying, a solar reflector made of 672 ft^2 of aluminized plastic was placed flat on the ground in front of the building (south side) to augment the solar energy striking the south wall. Monitoring done before and after the placement of these reflectors indicated an 18% increase in the temperature of the drying air, an increase well worth the small cost of the aluminized plastic.

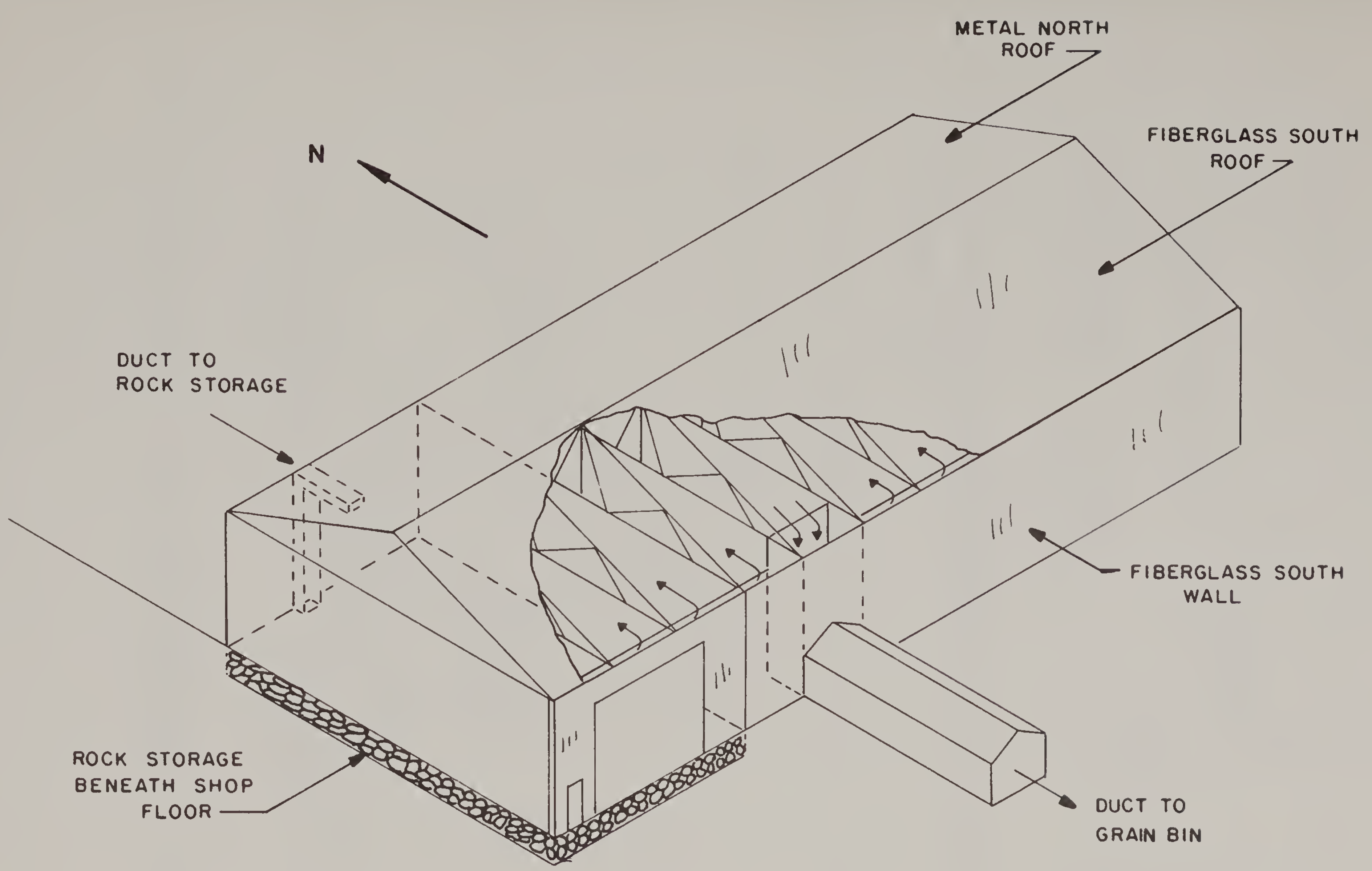


Figure 1. Isometric view of machine shed with solar attic on the Sass farm.

(Sass Farm)

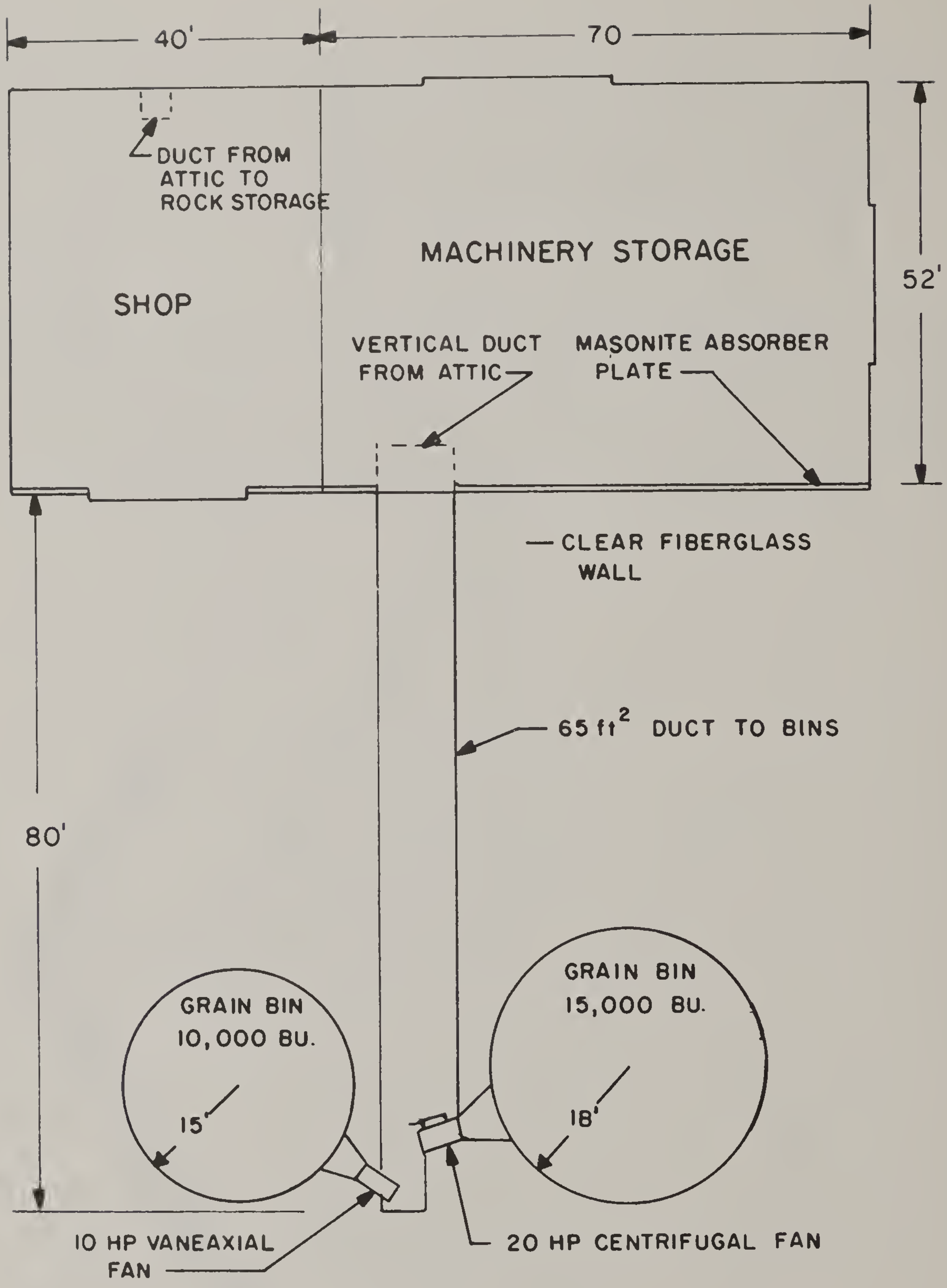


Figure 2. Plan view of drying bins and machine shed with solar attic on the Sass farm.

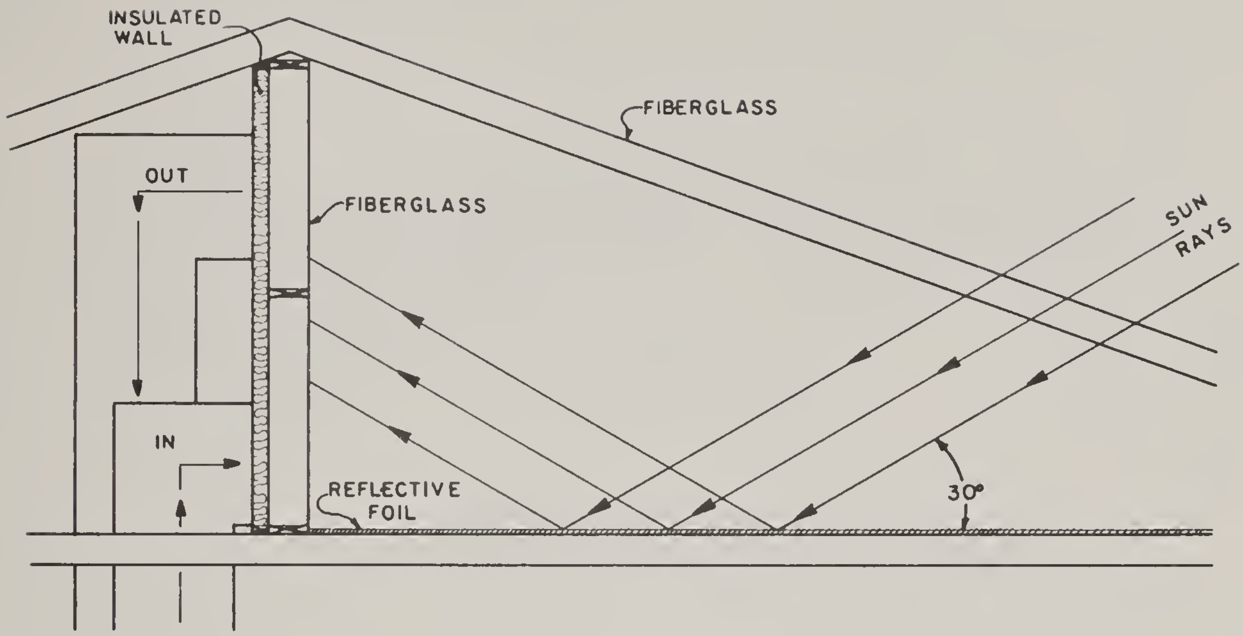


Figure 3. Cross section of solar collector with reflector in modified solar attic at the Sass farm.

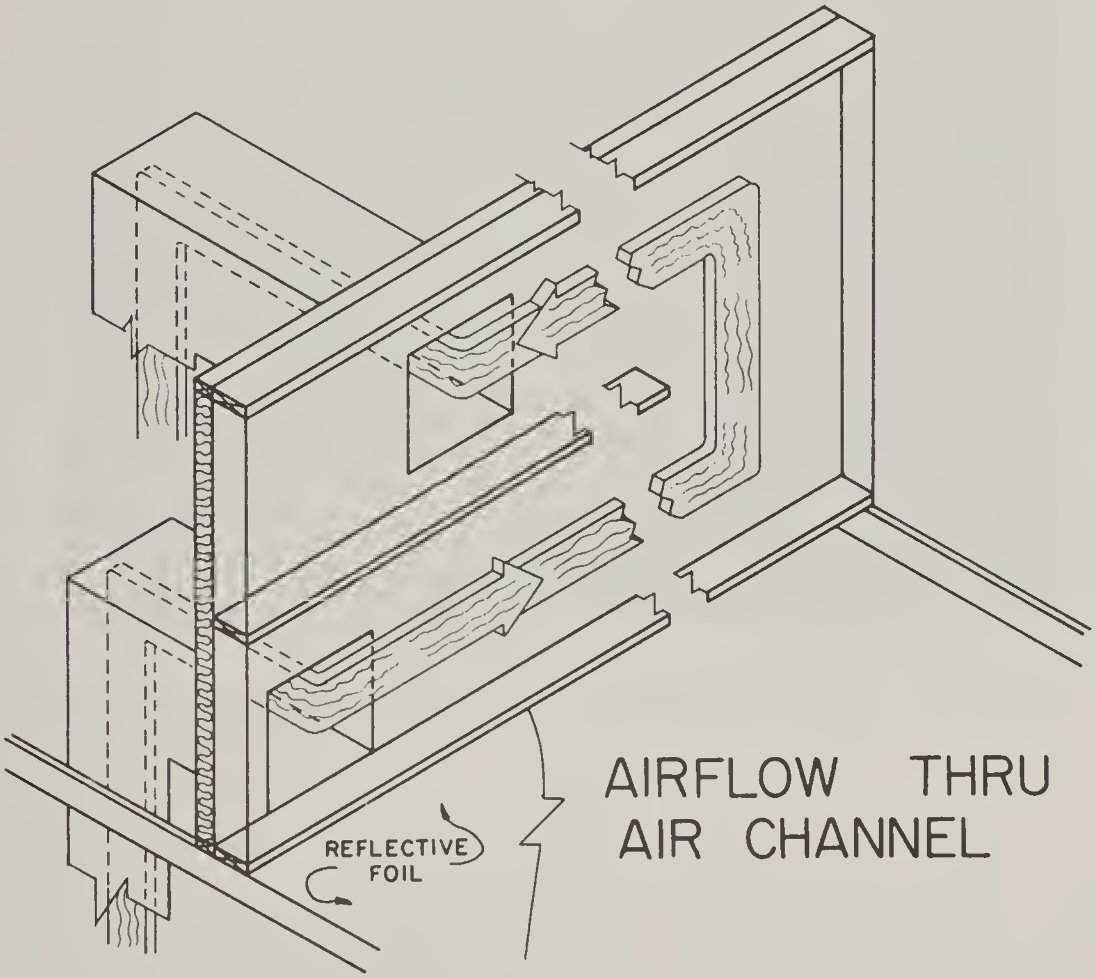


Figure 4. Detail of airflow in solar collector mounted in modified solar attic at the Sass farm.

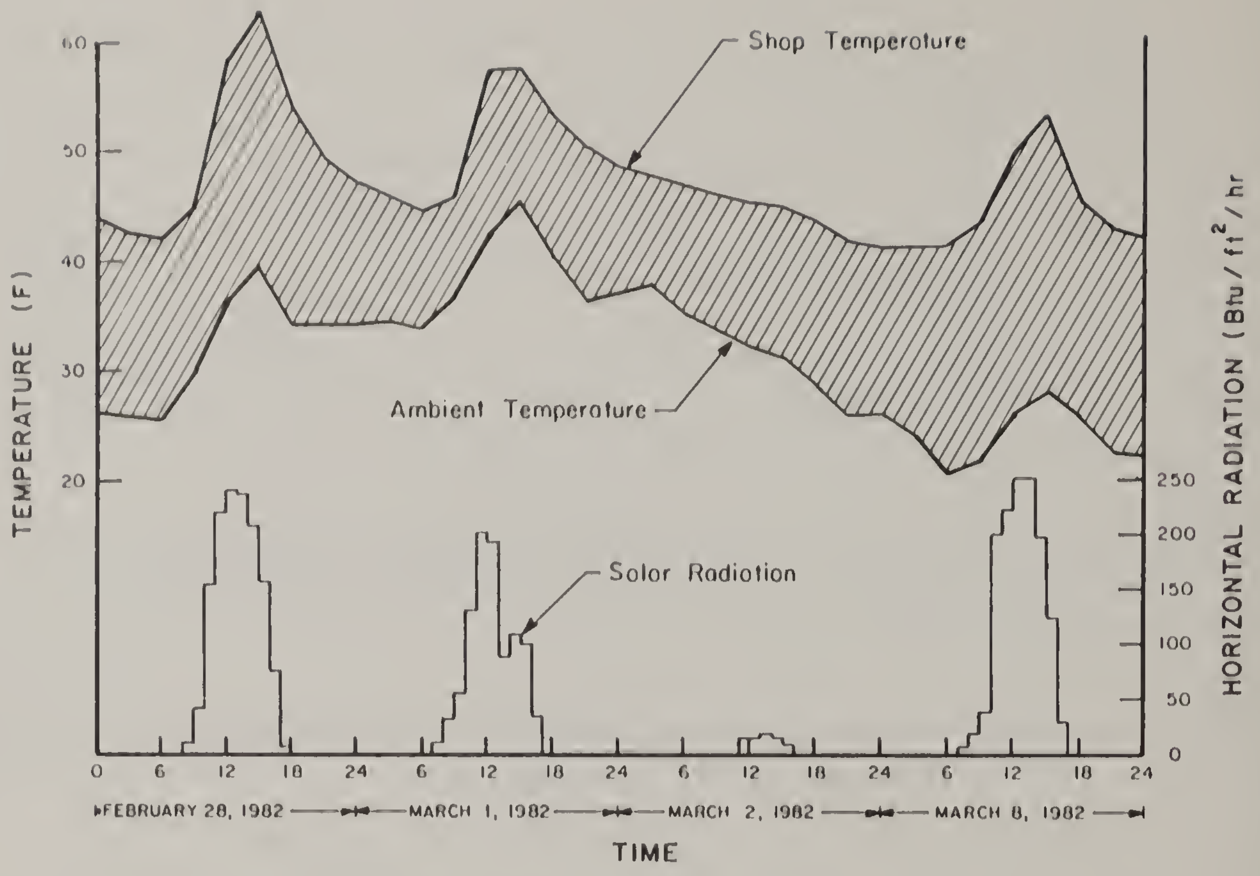


Figure 5. Typical sunny-day temperatures and solar radiation at the solar machine shed before attic modification at the Sass farm.

COOPERATIVE EXTENSION SERVICE

COLLEGE OF AGRICULTURE
UNIVERSITY OF ILLINOIS AT URBANA - CHAMPAIGN

HOT WATER SOLAR SYSTEM USED FOR BOTH GRAIN DRYING AND FLOOR HEATING IN SWINE FARROWING-NURSERY

Alfred Guebert
Red Bud, Illinois

Demonstration Project
On-Farm Solar Drying of Crops and Grains

Water-type solar collectors, in foreground, provide heat for swine farrowing-nursery building and drying bins.

HOT WATER SOLAR SYSTEM USED FOR BOTH GRAIN DRYING AND FLOOR HEATING IN SWINE FARROWING-NURSERY

THE FARM

The Al Guebert farm is located in southwestern Illinois. The present farming operation consists of a farrow-to-finish hog operation, in addition to cash grain crops of corn, soybean, and wheat. The grain drying facilities on the farm consist of two 6,000 bushel low temperature drying bins each equipped with a 10 hp vaneaxial fan and a stirring device. In addition to the drying bins, there are also three 3,300 bushel storage bins.

GOALS

The objective of this project was to demonstrate that a water type solar system designed to heat a swine farrowing-nursery building could also provide heat for the crop drying operation.

THE SOLAR SYSTEM

The solar system constructed in 1982 consists of thirty 3 ft. by 8 ft. water type collectors manufactured by Red Bud Industries Inc. The 720 ft^2 of solar collectors were designed to provide hot water floor heat to a 84 ft. by 85 ft. swine farrowing-nursery building. Because of the layout of the farm, the collectors had to be ground mounted on aluminum framework located approximately 80 ft. from the swine farrowing-nursery building. Heat storage for the collectors was provided by a 1,600 gallon insulated storage tank buried adjacent to the collector (Figure 1). Hot water from storage is piped through insulated underground pipes to the swine building when floor heat is required.

Solar heat for grain drying is provided by piping solar heated water from the swine building to a water-to-air heat exchanger mounted on the drying fan of the grain drying bin. The heat exchanger is moveable and can be used to provide heat to either of the two drying bins. Insulated above ground hose is used to pipe the water to and from the grain drying heat exchanger during the drying season and is then removed during the wintertime.

SOLAR SYSTEM COST

The cost of the Guebert solar system was as follows:

Solar Collector System for Swine Building -	$11,040
Additional Cost for Grain Drying -	578
Total Installation Cost -	5,520
Total -	$17,138

SOLAR SYSTEM PERFORMANCE

Because of excellent field drying conditions, little artificial drying of shelled corn was required on the Guebert farm during the 1982 monitoring year. On the bin set up for monitoring, one 5,590 bushel batch of corn was dried using solar heat. The corn in the bin was dried from 16.2% to 15.5% moisture content in a 65 hour drying period. During this time the drying fan used 540 kWh of electricity resulting in a drying efficiency of 0.138 kWh/bushel-point moisture removed. The operational procedure for using solar energy on the grain drying bin was to store solar heat in the hot water storage tank during the daytime, and then use the stored solar heat at nighttime to provide heat for grain drying. During the 65 hour drying period, 2.1×10^6 Btu of heat was supplied to the drying air over a two night period.

ECONOMIC EVALUATION

Because of the short amount of time the Guebert solar system was monitored for grain drying, it is difficult to determine a payback period for the grain drying portion of the solar system. But, because of the small investment for adding the grain drying option ($578) to the solar system and using average solar radiation values, the grain drying portion of the system should be paid back in less than two years.

COMMENTARY

More drying information is needed to determine the overall effectiveness of using the swine building solar system for drying grain. The system performed well during the short time it was needed in the 1982 drying season.

The solar drying system was designed with a temperature limiting thermostat on the grain bin to prevent drying temperature from becoming too high. This limiting thermostat caused the solar system to cycle off and on when in use. A more efficient procedure of operation would be to let the solar system operate continuously, providing all the heat it is capable of providing to the grain drying air.

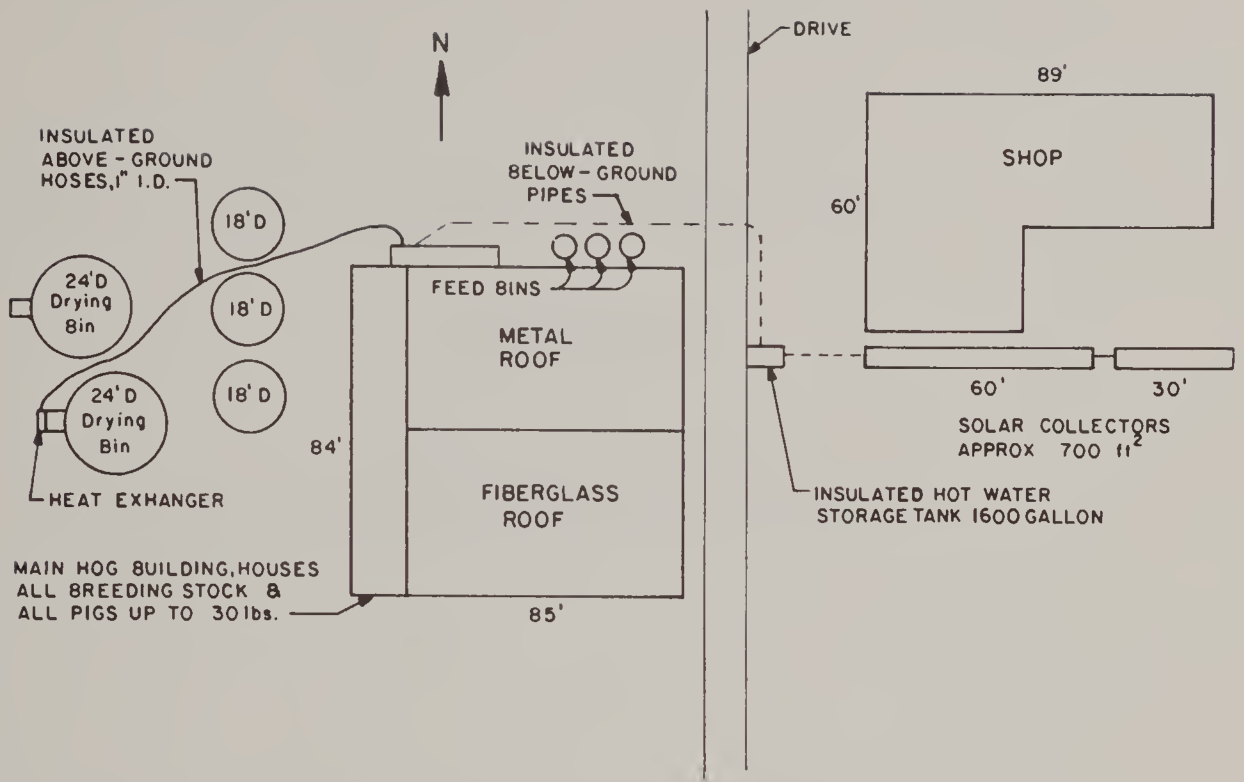


Figure 1. Plan view of arrangement of solar collectors, swine building, and drying bins at the Guebert farm.

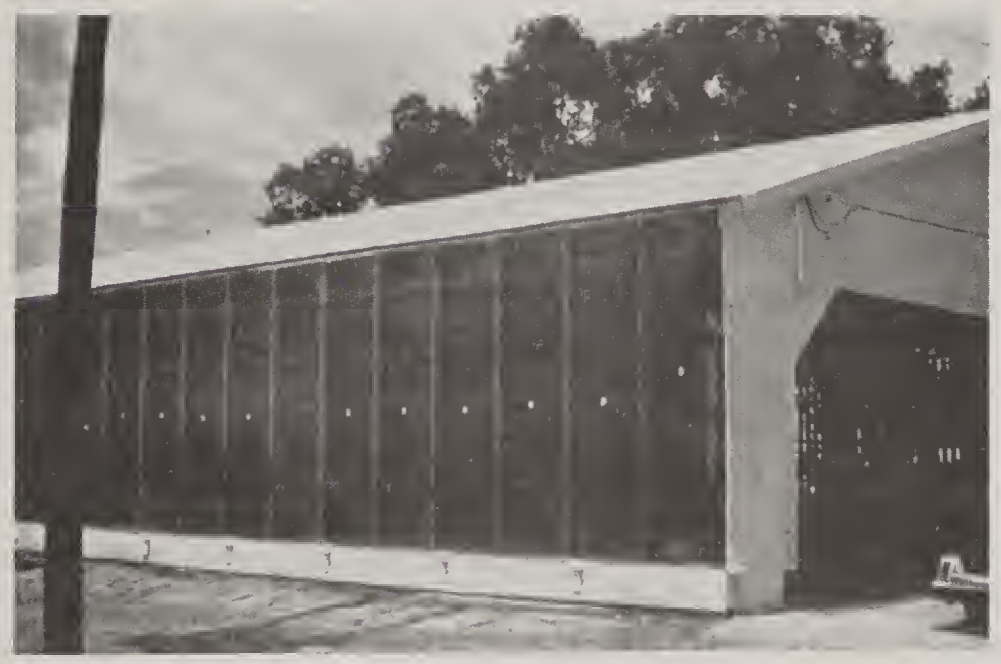
COOPERATIVE EXTENSION SERVICE

COLLEGE OF AGRICULTURE
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

SOLAR DRYING OF HAY IN LARGE BALES

Vernon Vahlkamp
Carlyle, Illinois

Demonstration Project
On-Farm Drying of Crops and Grains



Rigid-frame solar hay drying building, with 9500 ft^2 of solar collector incorporated into entire roof and south wall.

SOLAR DRYING OF HAY IN LARGE BALES

THE FARM

The Vernon Vahlkamp farm located in southwestern Illinois consists of 220 acres of commercially grown alfalfa. A solar hay drying barn constructed in 1977 permits timely harvest in the commercial haying operation and also provides a high quality hay to the dairies served by the Vahlkamp farm.

GOALS

The goal of this demonstration was to obtain operational data on the existing hay drying building and to make the solar collector on the hay drying building multi-functional by using it to provide space heat and hot water to the nearby farm home.

THE SOLAR SYSTEM

The solar hay drying building is a 45 ft. by 145 ft. rigid frame structure with 9,500 ft^2 of covered plate collector built into the north and south roof slopes and the south wall. The solar collector was formed by attaching black painted plywood absorber sheets to the underside of the rigid roof frames and to the interior side of the south wall. Clear corrugated fiberglass, used as the roofing material and south wall exterior covering, served as the solar collector cover material. Nine 5.0 hp centrifugal drying fans located in the south wall collector air cavity pull air over the roof and down the south wall through the air space created between the fiberglass and the plywood. The solar heated air is then blown through air ducts located under the building floor and into wet hay bales located inside the building (Figure 1). The building can presently dry 36 2500 lb round hay bales at a time.

To provide a winter-time function for the hay drying building collector, a second collector is being constructed inside the collector air cavity located in the south wall of the building. This second collector is a single cover suspended plate collector designed for air movement behind the absorber plate. This collector is formed by attaching 2 in. by 8 in. boards horizontally to the inside of the building posts. Urethane insulation board one inch thick is placed between the boards to form the back of the solar collector (Figure 2). Twenty guage aluminum sheets are attached to the boards to form the collector absorber plate, and then clear corrugated fiberglass is attached over the aluminum sheets to complete the collector. The secondary collector consists of two 4 ft. by 100 ft. sections, one above the other, giving a total collector area of 800 ft^2.

Two air-to-water heat exchangers located in the secondary collector will be used to transfer heat away from the collector. Air circulated by blowers located in the heat exchangers will move in a continuous

circle through the two collector sections. An antifreeze solution of propylene glycol will carry heat from the heat exchangers through underground insulated pipes to the farm home located 130 ft. away. In the basement of the farm home, heat will be transferred to a 400 gallon water storage tank via a finned coil (Figure 3). A water-to-air heat exchanger will be used to draw heat from the storage tank for space heating, and a small submerged preheat tank in the storage tank will provide hot water preheat.

SOLAR SYSTEM COSTS

The cost of the solar hay drying building constructed in 1977 was as follows:

Building -	$15,000
Grates and Ducts for Bale Drying -	11,000
Fans -	8,000
Plywood, Concrete, Fiberglass, Excavation -	12,000
Total -	$46,000

In addition, the house heating solar system being constructed into the hay drying building will cost $6,000 in materials.

SOLAR SYSTEM PERFORMANCE

The solar hay drying building was monitored from mid-July thru August in 1982. During this period, conditions were favorable for field drying alfalfa, hence the building was only completely filled once with wet hay during the monitoring period. During this one complete filling, 36-2,500 lb bales of 35-40% moisture content hay was dried in 75 hours. During the 75 hours drying period, 1.64×10^7 Btu of heat energy was collected by the solar collector for an energy equivalent of 180 gallons of LP-gas. During the entire 1982 haying season, a total of 300 tons of hay were dried in the building. Table 1 shows the sunny day performance of the hay drying building solar collector.

ECONOMIC EVALUATION

The true economic benefit of the Vahlkamp solar hay drying building is in the hay crops saved by being able to harvest and dry wet hay. Since the dollar value of saved hay crops is difficult to estimate, the simple payback for the Vahlkamp building was estimated using the dollar value of the heat energy collected by the solar collector. Assuming that the hay drying building operates 30 days out of the haying season, an average of 1.75×10^8 Btu per year of heat energy would be collected by the collector for an energy equivalent of 1,910 gallons of LP-gas. Assuming the cost of incorporating solar into the building as $7,500 (additional cost of fiberglass over metal roofing plus additional cost of plywood absorber plate) the simple payback period would be 5.2 years for the solar collector with 75¢ per gallon LP-gas.

Table 1. Mid-Summer Collector Performance Drying Hay (Vahlkamp Solar Collector)

Time	Horizontal Insolation Btu/ft^2-hr	Temperature Rise (°F)	Energy Collected (Btu/hr)
7:00	6.5	1.4	54,400
8:00	26.2	2.6	101,100
9:00	48.0	3.8	147,700
10:00	63.3	2.8	108,900
11:00	187.8	10.4	404,400
12:00	296.9	19.9	773,700
1:00	310.0	23.7	921,500
2:00	301.3	26.5	1,030,300
3:00	275.1	24.0	933,100
4:00	233.6	20.6	800,900
5:00	179.0	16.5	641,500
6:00	107.0	6.8	264,400
7:00	32.7	2.0	77,800
			Total - 6,259,700 Btu

Collector Airflow - 36,000 cfm
Total Energy Collected - 6,259,700 Btu
Solar Energy Available - 15,570,000 Btu
Efficiency - 40%

COMMENTARY

The Vahlkamp solar hay drying building has proved to be an important management tool in the Vahlkamp haying operation. Because of the large quantities of heat required to remove moisture from hay, energy costs for such an operation would be prohibitive if conventional heat sources were used. The design of the building allowed the solar collector to be easily incorporated, and due to the sheer size of the collector (9,500 ft^2) large quantities of solar heat can be collected and used in the drying process.

Some weathering has occurred on the corrugated fiberglass roofing sheets allowing some of the fiberglass fibers to become exposed through the plastic resin in the sheets. This problem is being corrected by resurfacing the sheets using a resurfacing resin obtained from the fiberglass manufacturer.

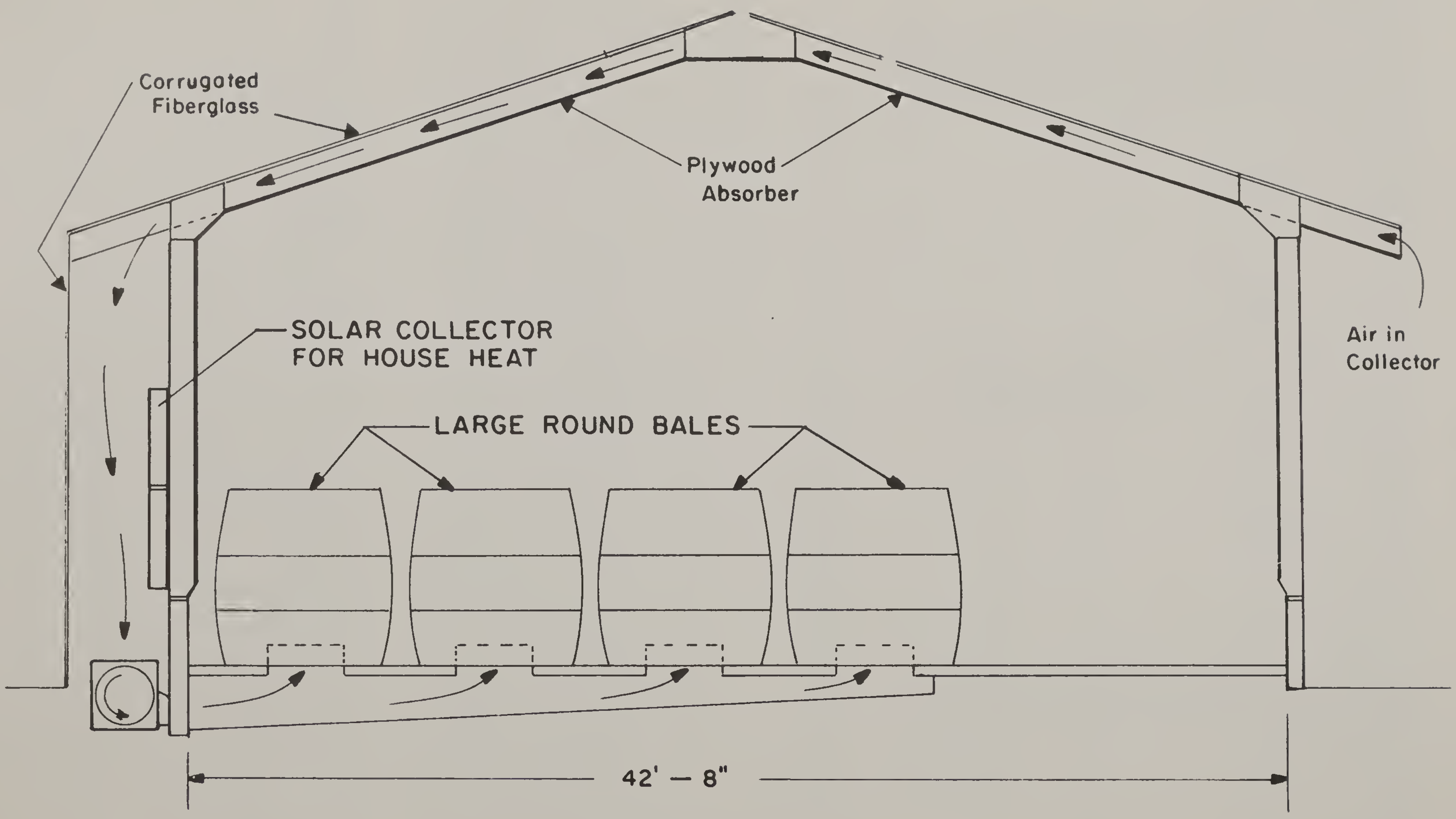


Figure 1. Cross section of solar drying building at Vahlkamp farm.

(Vahlkamp Farm)

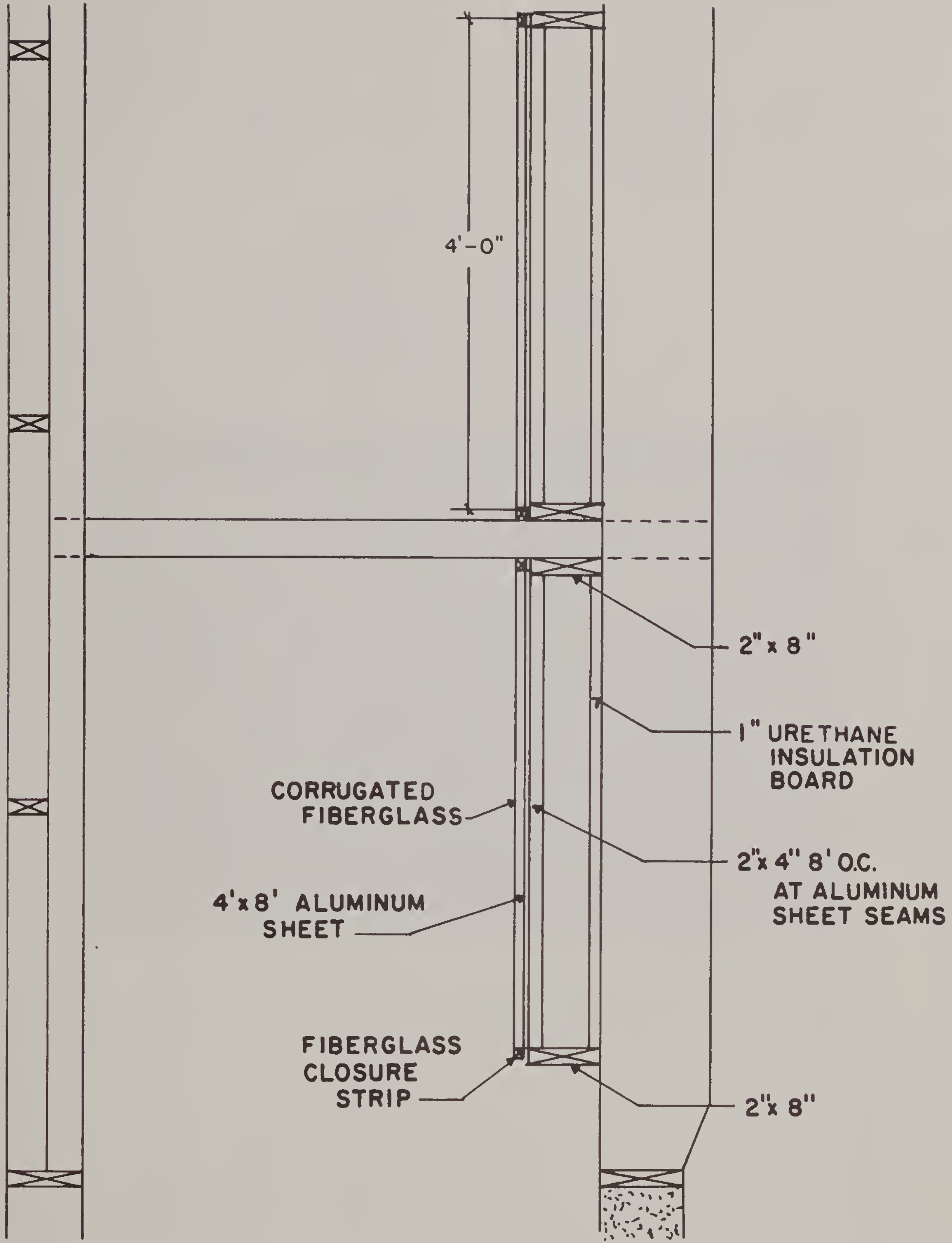


Figure 2. Detail of solar collector inside the south wall cavity of the solar drying building on the Vahlkamp farm.

(Vahlkamp Farm)

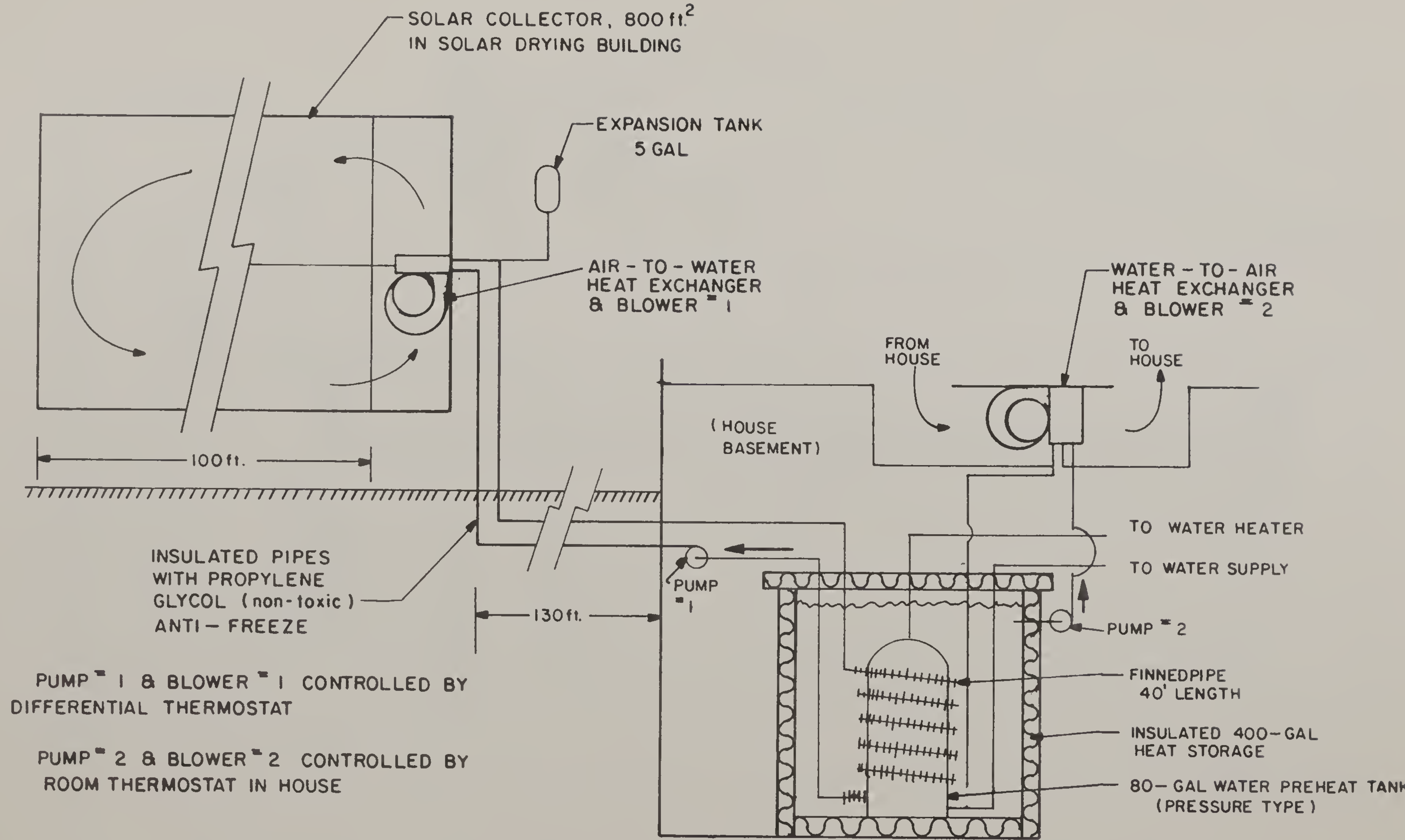


Figure 3. Functional diagram of the solar house heating system at the Vahlkamp farm.

(Vahlkamp Farm)

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COOPERATIVE EXTENSION SERVICE

COLLEGE OF AGRICULTURE
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

A SOLAR BIN-IN-BUILDING FOR DRYING AND SHOP HEATING

Dale Steffen
New Boston, Illinois

Demonstration Project
On-Farm Solar Drying of Crops and Grains

Building with South Roof and South wall covered with fiberglass for collecting energy for the drying bin inside the building and for shop heating.

A SOLAR BIN-IN-BUILDING FOR DRYING AND SHOP HEATING

THE FARM

The Dale Steffen Farm is a corn-soybean farm located in western Illinois. Grain drying facilities on the farm consist of a 9,000 bushel solar drying bin and a 20,000 bushel low temperature drying bin.

GOALS

The primary objective of this demonstration site was to show that a grain bin located inside of a fiberglass covered machine shed can be an economically feasible method for drying corn with solar heated air. A secondary objective was to improve the design of the building so that solar energy could be more effectively collected for the wintertime heating of a farm shop located inside the building.

THE SOLAR SYSTEM

A 36 ft. by 68 ft. pole building was used for the bin-in-building solar structure. Clear corrugated fiberglass was used as a cover material on the south half of the roof and on the south wall. A covered plate collector was formed into the south wall by constructing a secondary plywood wall inside the south wall poles to serve as a solar absorbing surface. The fiberglass covered south roof slope also allowed solar energy to enter the building passively, thus giving a total solar collector area of 2,380 ft^2.

The east 30 feet of the building was walled off and an insulated ceiling was constructed over this area to form a 30 ft. by 36 ft. shop area. In the west 38 feet of the building, a 33-foot diameter, 9,000 bushel grain drying bin was constructed without a roof. The bin is equipped with a 12.5 hp vane-axial fan which was set to pull air out of the drying bin and exhausts it outside the building (Figure 1).

During grain drying, air enters the building through a slot located in the south wall, travels up the wall between the fiberglass and plywood, and then enters the top of the grain bin. The solar heated air is then drawn down through the bin and exhausts from the building through the bin fan located outside the building.

As a secondary use, the solar collector is also used to heat the farm shop. Solar heated air can either be drawn directly out of the solar attic area located above the shop, or can be directed through 1 1/2 feet of 3 inch diameter rock located beneath the shop floor. The rock beneath the floor provides heat storage and also provides an indirect way of heating the shop area by warming the concrete floor (Figure 2).

To improve the efficiency of the solar system for shop heating, the solar attic area above the shop portion of the building is partitioned off from the rest of the building. In addition, an insulated wall is constructed down the middle of this attic area to prevent heat loss through the north half of the roof.

SOLAR SYSTEM COST

The total cost of the Steffen solar building including grain bin was $20,000.

SOLAR SYSTEM PERFORMANCE

The Steffen solar grain drying system was monitored both in 1981 and 1982. During each fall, two seperate batches of corn were dried in the solar drying system. Results from these two drying seasons are summarized in Table 1.

Table 1. Solar Drying Results from the Steffen Farm.

	1981	1982
Beginning Fill Date	9/21	9/26
Bushels Dried (bu)	17,300	15,700
Airflow (cfm/bu)	1.2	1.2
Initial Moisture (%)	21.7	21.8
Final Moisture (%)	16.7	17.0
Electrical Usage (kWh)	11,200	10,350
Drying Efficiency (kWh/bu-point moisture)	0.13	0.14

During 1981, the solar grain drying system operated from September 21 to November 24. During this period 4.97×10^7 Btu of heat energy was collected by the solar system for an energy equivalent of 543 gallons of LP-gas. The 1982 drying season lasted from September 26 to November 25. During this period 3.92×10^7 Btu of heat energy was collected by the solar system for an energy equivalent of 428 gallons of LP-gas. Table 2 shows the typical sunny day performance of the bin-in-building collector.

The Steffen building was also monitored for wintertime shop heating from February 10 to March 14, 1982 before shop heating modifications were made on the building. During this 33 day period, the solar system supplied 4.51×10^6 Btu of heat energy to the shop. The average collector efficiency over this period for shop heating was 4.5%. Assuming that the collector operated at this efficiency over a shop heating season from December to April, the total energy supplied to the shop by the collector would be 1.77×10^7 Btu, an energy equivalent of 193 gallons of LP-gas.

Table 2. Sunny Day Collector Performance (Steffen Solar Collector).

Time	Temperature Rise °F	Energy Collected (Btu/hr)
8:00	1.0	12,960
9:00	8.0	96,000
10:00	13.0	168,480
11:00	21.0	272,160
12:00	21.0	272,160
1:00	16.0	207,360
2:00	13.0	168,480
3:00	8.0	103,680
4:00	5.0	64,800
5:00	3.0	38,800
	Total -	1,404,960 Btu

Airflow - 12,000 cfm
Total Energy Collected - 1,404,960 Btu
Solar Energy Available - 4,151,000 Btu
Collector Efficiency - 34%

ECONOMIC EVALUATION

The total cost of the Steffen bin-in-building, constructed in 1977, was $20,000. To calculate the actual solar cost of the building, the cost of the shop portion of the building plus the cost of a grain drying bin with roof was subtracted from the initial building cost. Using the "1977 Agricultural Building Cost Guide" to estimate the cost of these two components, the following estimated solar cost was found:

Initial Solar Building Cost:		$20,000
Conventional Grain Drying Bin Cost:	-	12,400
Conventional Shop Cost:	-	4,100
Solar Cost:		$ 3,500

During the two years of monitoring, the solar system supplied an average of 4.45×10^7 Btu per year of heat energy to the grain drying air for an LP-gas equivalent of 486 gallons. An additional energy equivalent of 193 gallons of LP-gas is supplied by the collector for shop heating. Assuming 75¢ per gallon LP-gas the simple payback for the bin-in-building is:

Dollars Saved: 486 gallons x 75¢/gallon = $365 (Grain Drying)
193 gallons x 75¢/gallon = $145 (Shop Heating)
Total per year = $510

Simple Payback: $3,500/$510 = 6.9 years

COMMENTARY

The main advantage of the bin-in-building design is based on the price differential between a grain bin with a roof and a grain bin without a roof. In many cases, this price differential pays a major portion of the cost of constructing a solar building to house the roofless bin. The major disadvantage with such a system is that more careful management is required to insure properly dried grain. The wettest grain during drying is at the bottom of the bin because drying air movement is downward through the bin instead of upward. Detection of spoilage is difficult since any spoilage will occur in this wet grain at the bottom of the bin.

The Steffen solar drying system dried grain efficiently during the two years of monitoring. Corn was stored in the building through the warm summer months with no spoilage problem resulting. The solar shop heating system did not provide the energy that was potentially available for shop heating. Modification being made to the building to reduce collector heat loss plus a larger volume fan being installed should greatly improve the effectiveness of the collector for heating the shop area during the wintertime.

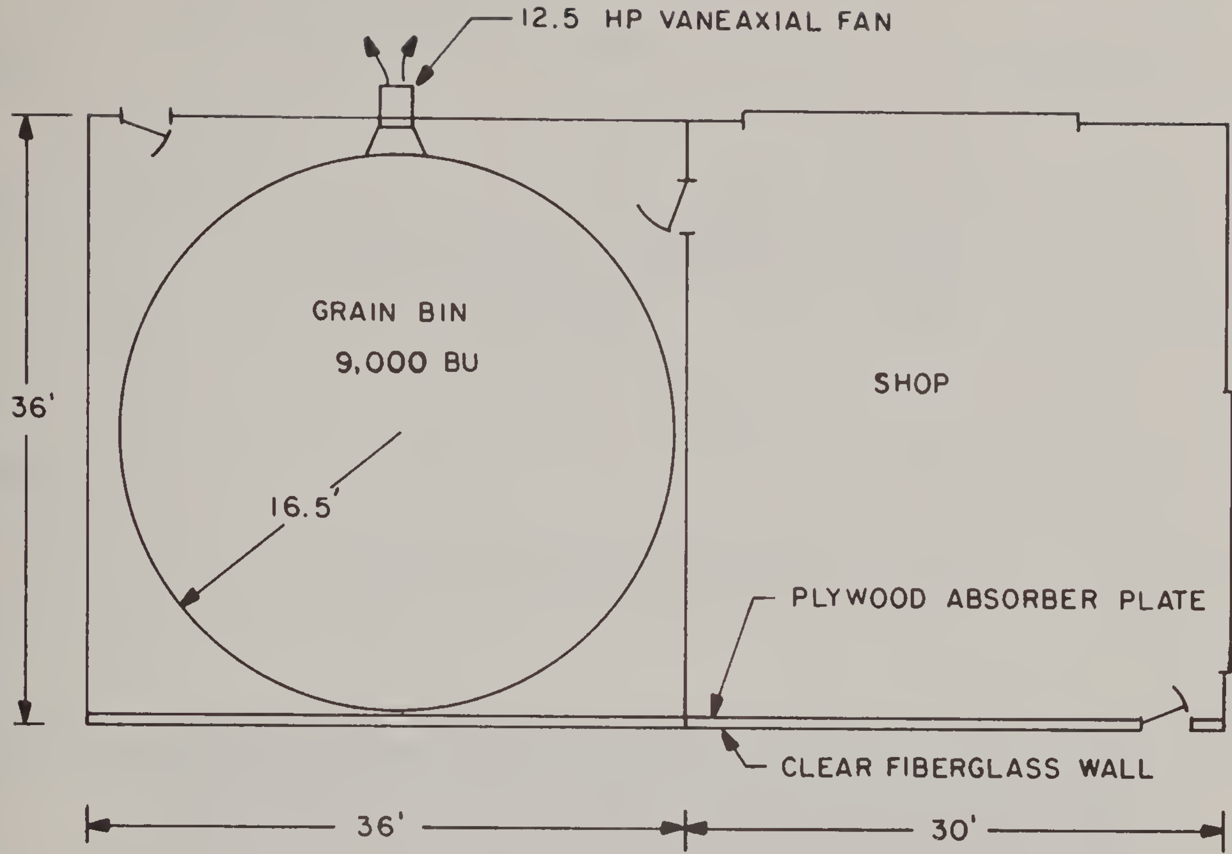

Figure 1. Plan view of solar bin-in-building showing drying bin and shop locations on the Steffen farm.

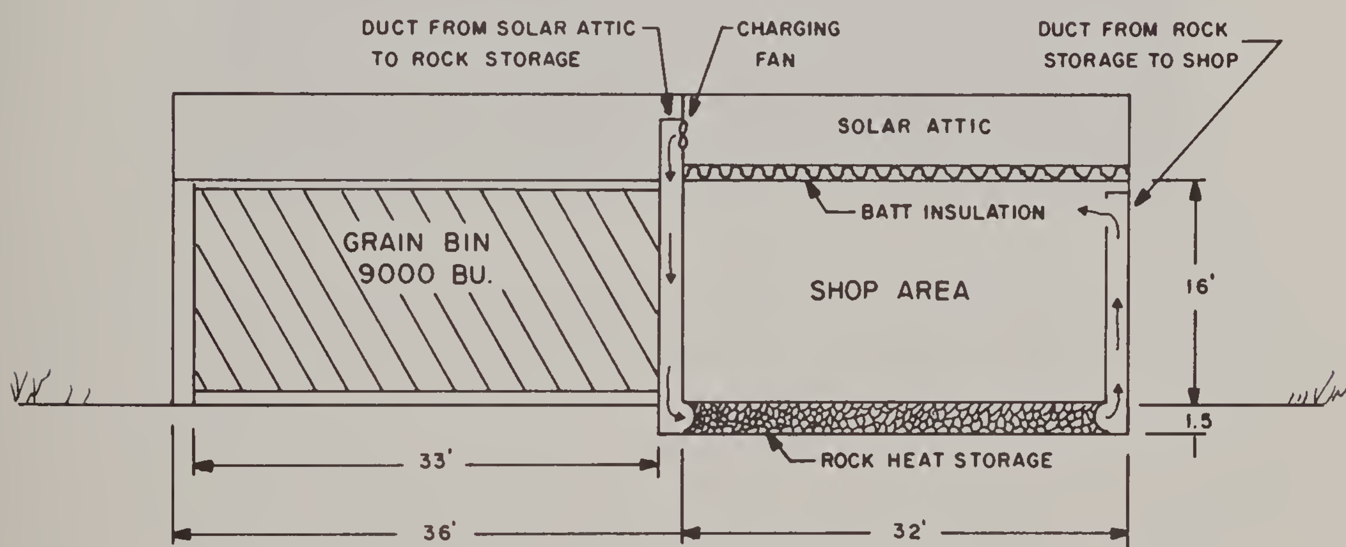

Figure 2. South cross-section view of solar bin-in-building on the Steffen farm.

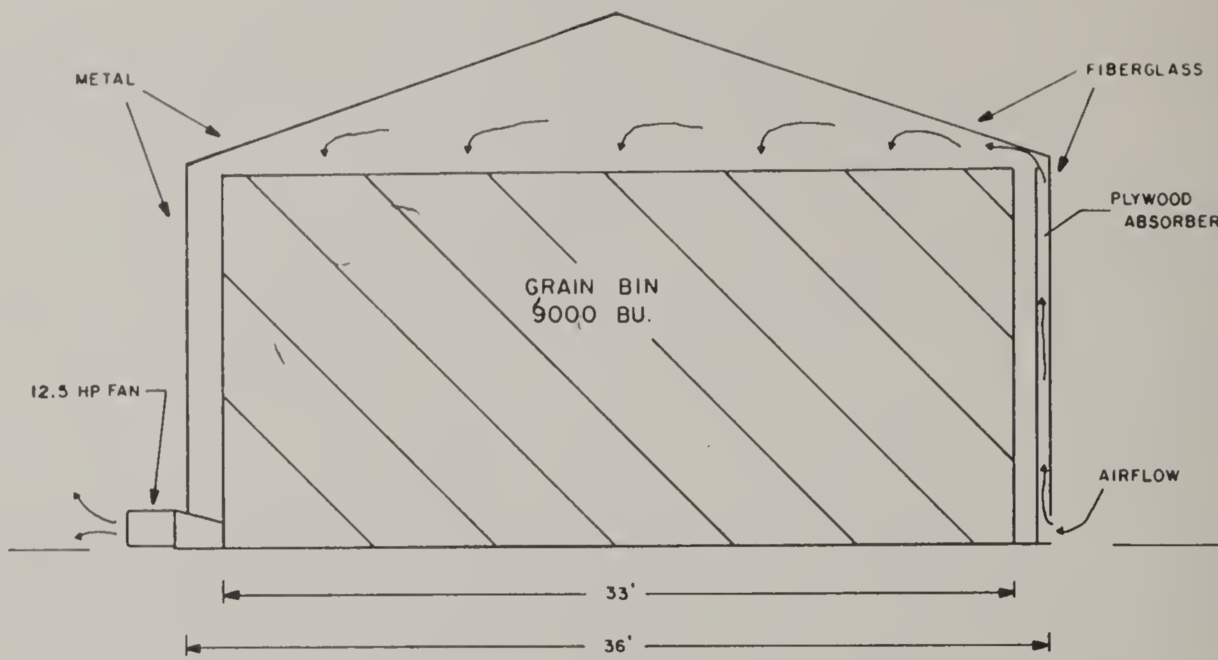

Figure 3. West cross section of drying bin in solar bin-in-building on the Steffen farm.

COOPERATIVE EXTENSION SERVICE

COLLEGE OF AGRICULTURE
UNIVERSITY OF ILLINOIS AT URBANA - CHAMPAIGN

A SOLAR COLLECTOR ON A SWINE FINISHING HOUSE FOR CROP DRYING AND NURSERY HEAT

Rodney Lindsey
Rio, Illinois

Demonstration Project
On-Farm Solar Drying of Crops and Grains

Solar heated air from the "partial attic" of the swine finishing building is moved through an underground tunnel to the drying bin. On winter days, heat is stored in the shelled corn for use in the nursery at night.

A SOLAR COLLECTOR ON A SWINE FINISHING HOUSE FOR CROP DRYING AND NURSERY HEAT

THE FARM

The Rodney Lindsey farm is located in west central Illinois. The present farming operation consists of a large farrow-to-finish hog operation, in addition to cash grain crops of corn and soybeans. The grain drying facilities on the farm consist of a continuous flow dryer and 23,000 bushels of storage, plus two 15,000 bushel low temperature drying bins.

GOALS

The primary objective of this project was to demonstrate that solar heated air from a solar attic located in a hog finishing building could be ducted to a drying bin and be used for low temperature grain drying. The secondary objective was to show that corn stored in the drying bin could provide a heat storage medium for storing excess solar heat collected by the attic collector on sunny winter days.

THE SOLAR SYSTEM

A 144 ft. by 45 ft. hog finishing building built in 1979 was constructed with an insulated solar attic incorporated into the south half of the roof. The 3415 ft^2 collector was formed by partitioning and insulating the south half of the attic space in the building and by using clear corrugated fiberglass as the roofing material on the south half of the roof. Before 1981, the solar attic was used only to preheat ventilation air entering an adjacent hog nursery building. In 1981 a 36 ft. diameter, 15,000 bushel drying bin equipped with two 20 hp centrifugal fans was constructed adjacent to the finishing building. A 3 ft. by 4 ft. underground duct of reinforced concrete was constructed to draw solar heated air from the solar attic to the drying bin to provide heated air for drying (Figure 1).

To make use of excess solar heat available in the wintertime for heating the adjacent nursery building, the ducting system to the bin was designed so that corn in the bin could be used as a heat storage medium. During the daytime, excess solar heat can be drawn from the solar attic and forced over to the grain bin with a 4,000 cfm fan located in the duct. During the nighttime, a 1,350 cfm fan draws air back from the bin to the nursery building utilizing heat stored in the corn to heat this air. The 65 ft. long underground duct from finishing building to the bin was insulated to reduce heat loss.

SOLAR SYSTEM COST

The cost of the solar system plus modifications was as follows:

(Lindsey Farm)

Solar attic in finishing building:	$1,500
Cost of Tunnel, Labor & Fans:	8,000
Total:	$9,500

SOLAR SYSTEM PERFORMANCE

The Lindsey solar grain drying system was monitored both in 1981 and 1982. In both years the performance of the 15,000 bu. solar drying bin was compared to an identically sized no-heat drying bin also equipped with two 20 hp drying fans. Drying results from these two years are summarized in Table 1.

Table 1. Solar Drying vs. No Heat Drying on the Lindsey Farm.

	1981		1982	
	Solar Drying	No Heat Drying	Solar Drying	No Heat Drying
Beginning Fill Date	10/19	11/5	9/30	10/2
Bushels Dried	14,700	13,800	15,500	16,300
Airflow (cfm/bu)	1.7	1.8	1.5	1.3
Initial Moisture (%)	21.1	21.9	24.3	20.0
Final Moisture (%)	14.9	16.2	15.5	15.3
Electrical Usage (kWh)	22,900	35,400	41,500	34,000
Drying Efficiency (kWh/bu-point moisture)	0.25	0.45	0.30	0.44

During 1981, the solar grain drying system operated from October 19 to November 19. During this time, 3.11×10^7 Btu of heat energy was collected by the solar system for an energy equivalent of 340 gallons of LP-gas. During 1982 the system operated from September 30 to November 27. During this period, the solar system collected 4.26×10^7 Btu of heat energy or an energy equivalent of 465 gallons of LP-gas. Table 2 shows the daily collector performance for drying corn on a typical sunny day.

ECONOMIC EVALUATION

The total cost of the Lindsey solar system, including fan and controls necessary to use the grain bin as a heat storage unit was $9,500. The energy cost reduction for drying corn in the solar system compared with what it would have cost to dry the same corn in the no heat drying bin averaged $1,100 per year less (assuming 6¢/kWh electricity) for the two monitoring years. This $1,100 per year savings results in a simple payback period of 8.6 years for the solar system using the benefits derived for the solar drying alone. The solar heat storage system was not completed until the spring of 1982 hence no monitoring information is available to determine the economic benefits of the grain bin heat storage setup. It is anticipated that the economic benefits of the heat storage setup will greatly shorten the simple payback period.

(Lindsey Farm)

Table 2. Sunny Day Collector Performance for Grain Drying (Lindsey Solar Collector)

Time	Temperature Rise 1/ (°F)	Energy Collected (Btu/hr)
8:00	0.9	25,700
9:00	1.8	51,300
10:00	3.2	91,200
11:00	4.1	116,900
12:00	6.7	191,000
1:00	5.8	165,400
2:00	7.4	211,000
3:00	6.7	191,000
4:00	5.4	154,000
5:00	4.1	116,900
6:00	2.1	59,900
	Total -	1,374,300 Btu

Total Energy Collected - 1,374,300 Btu
Solar Energy Available - 5,116,570
Collector Efficiency - 27%

1/Temperature rise at drying fans.

COMMENTARY

The Lindsey solar drying system performed well during the two years of operation. Drying costs for the solar drying bin averaged 37% less per year than the costs for the no heat drying bin.

One objective when building the underground tunnel on the Lindsey system was to construct a lower cost tunnel than the conventionally used steel round culvert tunnel. To accomplish this, a three sided 3 ft. by 4 ft. reinforced concrete duct was constructed in a trench and was then covered to form the underground tunnel. The material costs for the concrete tunnel were lower than road culvert costs, but the labor costs involved in forming the concrete duct resulted in a much higher priced tunnel than would have resulted using road culvert.

One problem encountered with the tunnel after construction was water accumulation in the tunnel due to poor drainage. This problem was eliminated by constructing an outlet from the lower end of the tunnel to remove excess water.

Because of the concern about the buildup of high summertime temperatures in insulated solar attics, a max-min surface thermometer was placed in the peak of the finishing building solar attic. The maximum temperature reached in 1982 was 192°F. Such high temperatures should be avoided if possible and can be reduced in the Lindsey building by providing more summertime venting.

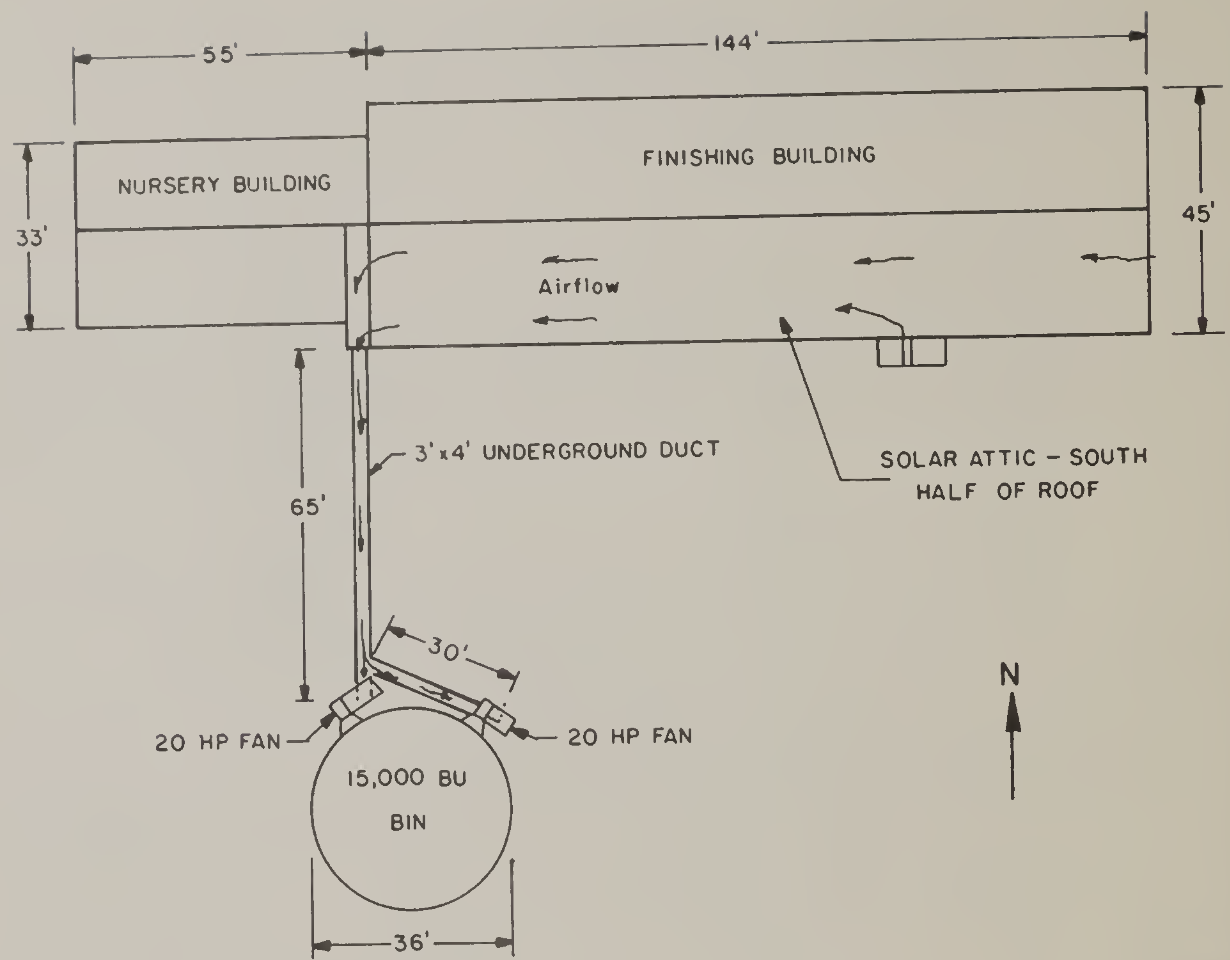

Figure 1. Plan view of drying bins, finishing building, and nursery building on the Lindsey farm.

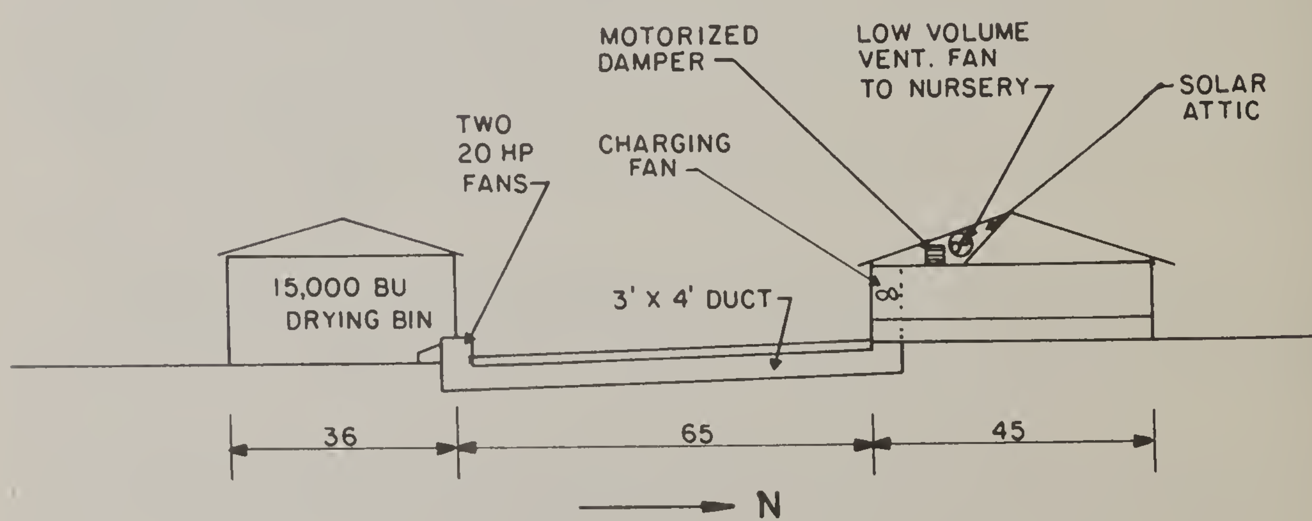

Figure 2. Cross section view of solar system and drying bins showing underground duct at the Lindsey farm.

180

245

KANSAS FINAL REPORT

SOLAR GRAIN DRYING DEMONSTRATIONS

USDA AGREEMENT
NO. 12-05-300-509
KSU PROJECT NO. 60810-0816

BY

John A. Anschutz
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KANSAS STATE UNIVERSITY
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CONTENTS

Abstract

Ten on-farm solar grain drying demonstrations were monitored during the fall of 1982 to determine economic and technical feasibility. A total of 65,300 bushels of grain was dried with supplemental heat from 3,540 square feet of solar collector surface area built at a cost of $42,129.99. The average cost per square foot of collector was $11.89 of which $3.17 per square foot was allocated to the solar grain drying economic analysis.

The collector costs for grain drying ranged from $0.57 to $14.34 per square foot of the collector. Only four of the ten collectors proved to be economically viable (i.e. positive return on invested capital) for grain drying. Those four had an average cost of $1.53 per square foot with an 18% inflation-adjusted after tax annual return on invested capital. The six having negative returns had an average cost of $6.82 per square foot of collector.

The energy collected for the 1982 fall crop drying season was equivalent to 895 gallons of LPG. The average drying period lasted 31.5 days with an equivalent of 0.25 gallons of LPG being collected for each square foot of collector area. Overall seasonal collector efficiency was estimated at 45% based on an average year data.

Introduction

This final project report of the solar grain drying demonstrations in Kansas presents the results of the 1982 fall crop drying season for ten on-farm solar grain drying systems. The project was funded by the Cooperative Extension Service, Scientific and Education Administration, United States Department of Agriculture through Agreement no. 12-05-300-509.

The objectives of the project were to:

1. demonstrate the economic and technical feasibility of on-farm solar grain drying in Kansas.

2. where possible, demonstrate the solar energy technology developed under the DOE/USDA SEA federal research program.

3. show conservation techniques known to industry.

4. incorporate solar to minimize the interruption or interference in the normal operation of crop drying.

5. identify incentives and opportunities for wide spread farm application of solar energy technology.

Approximately 60 farmers were interviewed as potential cooperators for the projects. Ten were selected from this group which we felt would give us a wide variety of types, sizes, and costs of solar collectors as well as a variety of alternate uses when not drying grain.

The ten solar grain drying demonstrations for this project were:

1. Davis Farm
2. Gigstead Farm
3. Henke Farm
4. Keesecker Farm
5. Parmley Farm
6. Runft Farm
7. Schroeder Farm
8. A. Thompson Farm
9. G. Thompson Farm
10. Wahl Farm

Figure 1 show location of the ten cooperators. Encircled numbers on the State map correspond to the list above.

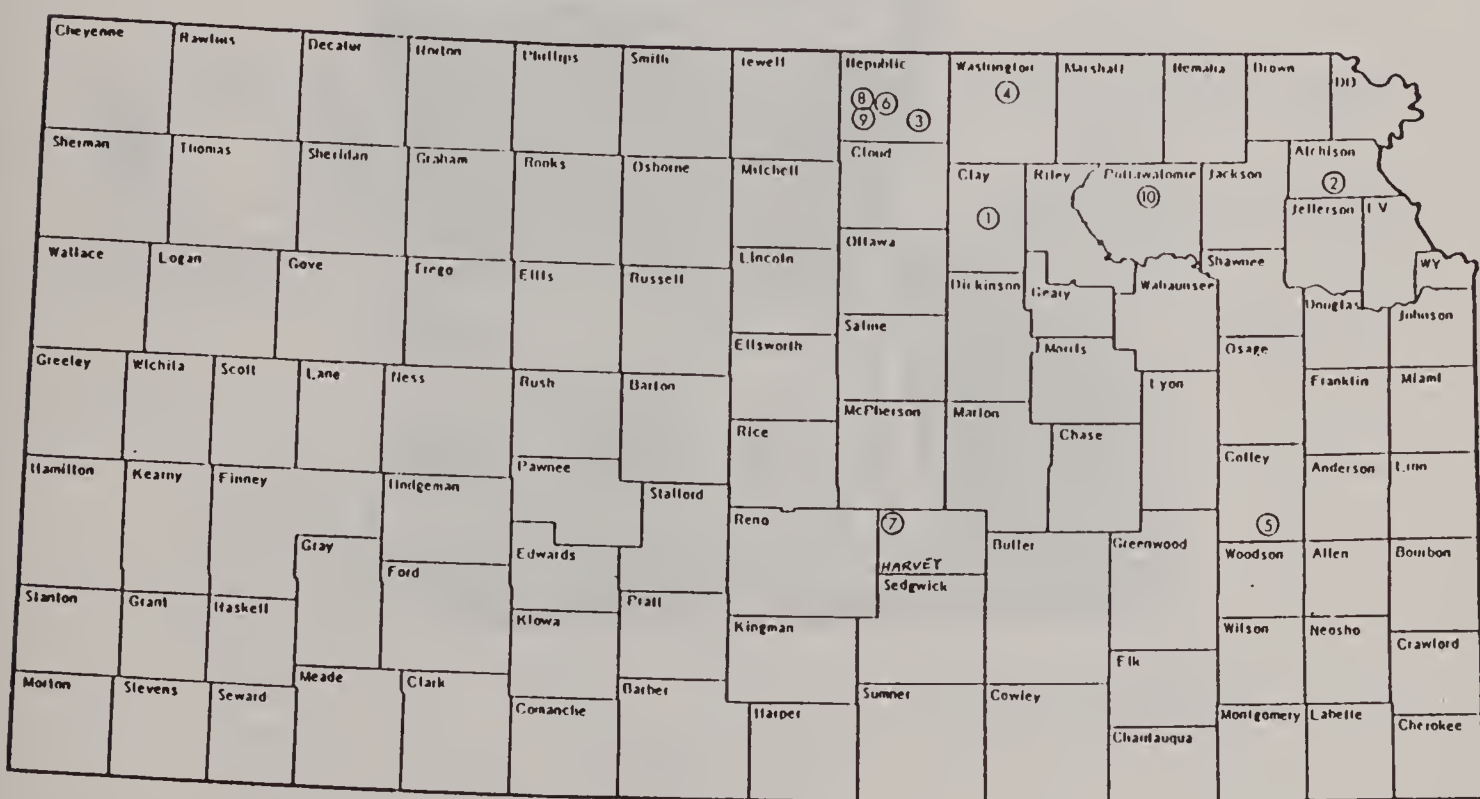


Figure 1

Data Collection

At each installation, sufficient hourly data were collected to determine the amount of solar energy supplied to the air by the solar collection system. These data included temperature increase and flow rate of the air through the collector. Ambient air temperature was also measured at each location.

The data were collected and recorded on audio cassette tapes by a micro-computer-based, Synertek model SYM-1, data logger shown in Photo 1. All sensors were sampled once per minute and the values were averaged for the hourly recorded value. Copper-Constantan thermocouples were used to measure temperature referenced to the data logger temperature. An Analog Device AD590 temperature sensitive integrated circuit was used to measure the temperature of the data logger to give the absolute values of the thermocouple readings. A Kurz hot wire anemometer shown in Photo 2 was used to measure airflow rates during periodic visits. Constant speed fans were used and airflow did not change significantly after grain bins were filled.

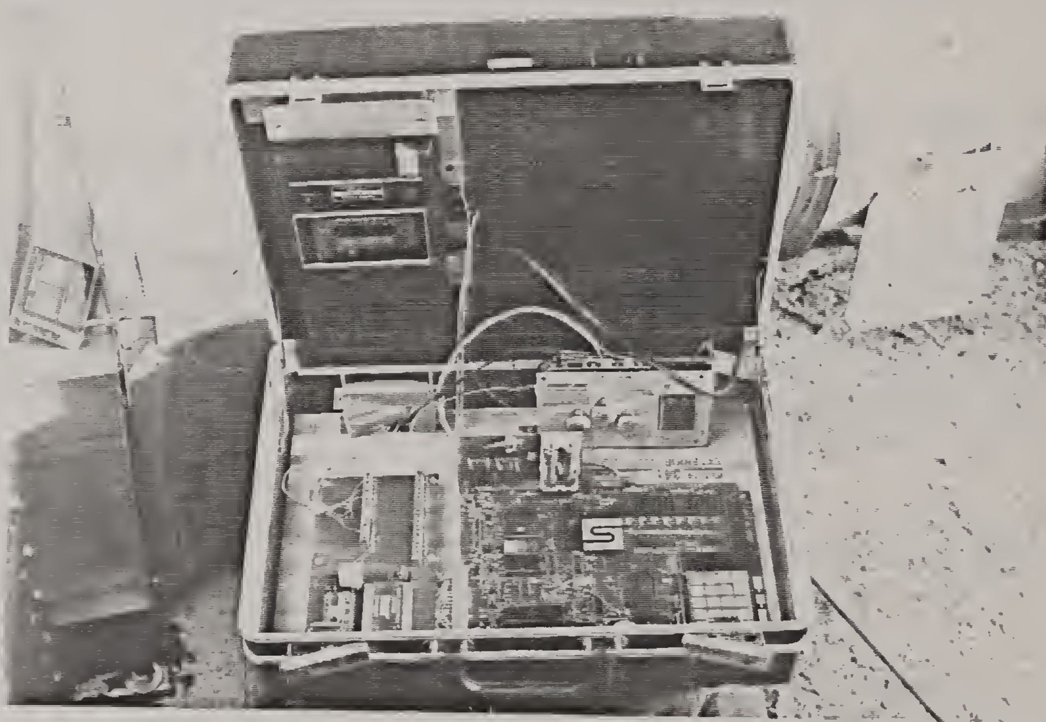


Photo 1

Life-Cycle Economic Analysis

A life-cycle economic analysis was performed on each individual collector to determine economic viability for the solar drying system. In each demonstration we determined the amount of energy saved and the the percent return on invested capital. We also predicted the amount of

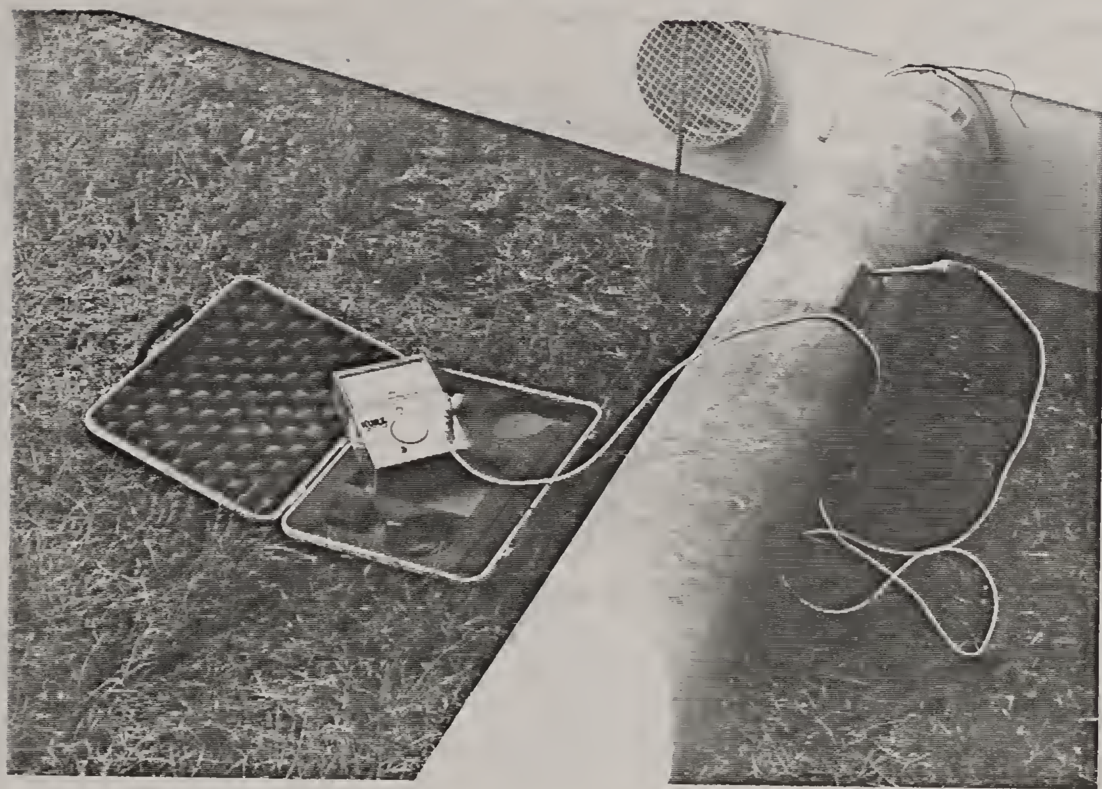


Photo 2

energy that would have to be saved in order to have a ten-year payback with zero return on the invested capital.

The energy saved was calculated base on an energy content of 92,500 Btu per gallon of LPG with a burner efficiency of 90%. All of the collected energy delivered to the bin was assumed to be usable.

The following economic parameters were used for all ten demonstrations:

Economic life: 10 years
Salvage value: 10% of collector cost
Energy tax credits:
15% Federal
30% State
Investment tax credit: 10%
Depreciation: Straight Line (cost - S.V)/10 per year
Type of fuel replaced: Liquified Petroleum Gas (LPG)
Initial fuel cost: 65¢ per gallon
Fuel cost escalation rate: 10%
General inflation rate: 7%
Marginal income tax bracket: 25%
Property tax and insurance rate: 3% of collector cost per year
Maintenance costs: 1% of collector cost per year

Obviously, the economic parameters would vary with each individual solar crop dryer and farmer, however by keeping them the same, economic

comparisons may be made among collectors. Collectors were cost shared with project funds for one-half of the collector system cost not to exceed $2,000. Cost share money was not deducted from the collector costs for the economic analysis. Twenty-five percent of the collector cost was apportioned to grain drying economic analysis for collectors with multiple uses. That value seemed reasonable since the average time the collectors were used for grain drying was 31.5 days. Only one collector was exclusively dedicated to grain drying. For that case, 100 percent of the collector cost was used in the economic analysis.

The economic analysis for each collector was based on data collected from only one drying season and should not be construed as being the economic viability over the life of the collector. It was merely used as a tool for comparison.

<u>Davis Solar Demonstration</u>

Robert Davis
Rural Route
Clay Center, KS 67432

Davis purchased a commercially made collector through a local dealer. The collector was manufactured by the Solar Search Corporation, Box 118, Cissna Park, Illinois 60924. It is a suspended flat plate collector with Filon 856 single layer glazing and a flatblack painted aluminum absorber plate. We did not attempt to determine efficiency of the collector, however, a test report done by Wile Laboratories indicated that the collector would be about 47 percent efficient when the input temperature to the collector is ambient, as is the case in the solar grain drying demonstration. Figure D1 shows the performance of the Solar Search collector as measured in accordance with ASHRAE 93-77.

The collector measuring 8 feet x 28 feet with a surface area of 22 square feet was purchased at a total cost of $6,306.04. Since the collectors alternate use was for heating the home, only 25% of that cost was apportioned to the grain drying economic feasibility analysis. This amounted to $7.04 per square foot of collector.

Measured Performance:

The solar collector was run for grain drying on five days during the period from October 5 through October 12, 1982. Davis chose to operate the collector only on sunny days during this period. The collector ran 46 hours total for grain drying and produce an equivalent of 0.05 gallons of LPG per square foot of collector. The airflow through the collector was 7.1 cfm per square foot of collector. Figure D2 shows the solar temperature rise obtained from the collector. The maximum temperature rise (Δ T) from this curve is 21° F. Using the equation:

$$\text{Btu/hr-ft}^2 = 1.1 \times \Delta T \times \frac{\text{cfm}}{\text{ft}^2}$$

we get

$$\text{Btu/hr-ft}^2 = 1.1 \times 21^{\circ}\text{F} \times 7.1$$

$$= 164 \text{ Btu/hr-ft}^2$$

Clear day radiation available to the collector during that time of the year would be about 300 Btu/hr-ft^2. Calculated efficiency would be given by the equation:

$$\text{eff} = \frac{\text{collected solar energy}}{\text{available solar energy}} \times 100\%$$

or

$$\text{eff} = \frac{164 \text{ Btu/hr-ft}^2}{300 \text{ Btu/hr-ft}^2} \times 100\% = 55\%$$

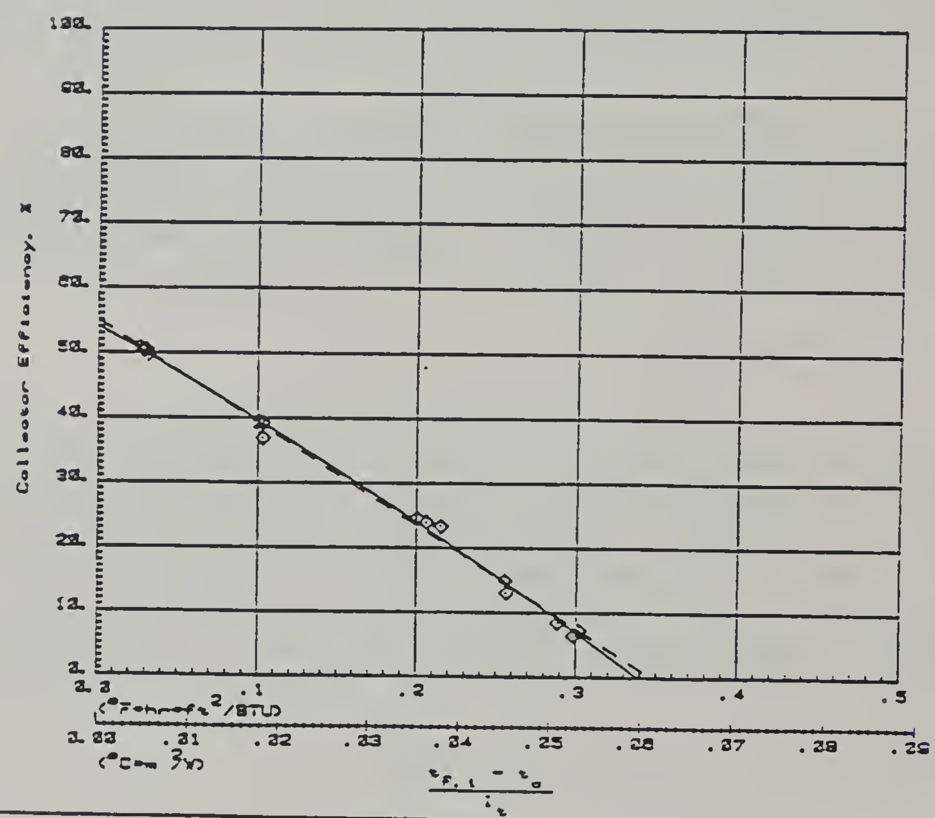
Our measured efficiency agrees quite well with the efficiency determined by ASHRAE standards. Grain Drying Operation:

TEST REPORT NO. 45526-1

SOLAR SEARCH CORP. JOB # 45526
POST STAGNATION THERMAL PERF. TEST
FLOW= 80SCFM GROSS AREA= 32.00SQ. FT

$$\eta_g = 0.550 - 1.586 \left(\frac{t_{in} - t_{amb}}{I_t}\right)$$ (1st Order) Dashed Line

$$\eta_g = 0.540 - 1.381 \left(\frac{t_{in} - t_{amb}}{I_t}\right) - 0.641 \left(\frac{t_{in} - t_{amb}}{I_t}\right)^2$$ (2nd Order) Solid Line



WYLE LABORATORIES
Huntsville Facility

Figure D1

A 5500 bushel drying bin with a 24 inch diameter 5 H.P. fan was filled with 3,000 bushels of grain sorghum with a moisture content of 19.5%. Solar heated air was ducted to the bin fan inlet through 18 inch diameter sheet metal duct approximately 20 feet long. The solar heated air was mixed with ambient air at the bin fan before entering the bin plenum. Total moisture removed from the grain was calculated to be 8,894 pounds. The energy provided from the collector would have evaporated 622 pounds of water or 7% of the total water removed.

Economic Feasibility:

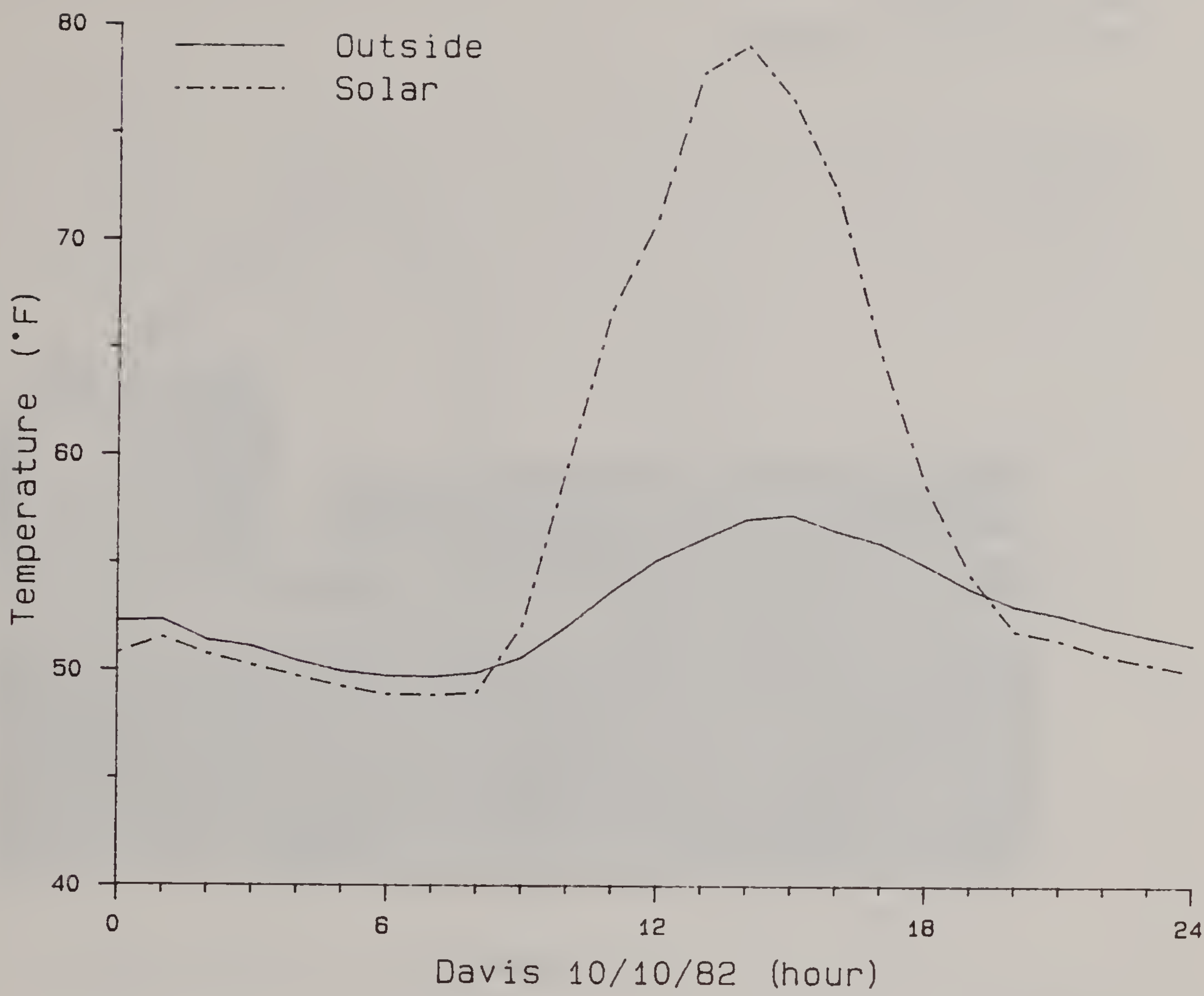


Figure D2

The energy collected was equivalent to 0.05 gallons of LPG per square foot of collector during the time the collector was used for grain drying. Using 25 percent of the collector cost apportioned to grain drying, our economic analysis gave a negative rate of return on the invested capital. The relatively high cost and the short time of use of this collector were major factors contributing to the negative return.

We determined from our economic analysis that 0.55 gallons of LPG per square foot of collector would have to be saved to have a 10 year payback for this collector. Davis plans to use the collector to heat his house when not drying grain.

Gigstead Solar Demonstration

Albert Gigstead
Rural Route 1
Nortonville, KS 66060

Photo G1

Collector:

The Gigstead demonstration utilized a 48 foot by 80 foot, east-west oriented machine shed for the solar collector. The collector was constructed on the south facing vertical wall of the machine shed. The absorber surface measuring 14 feet high and 80 feet long was constructed with 1/2 inch CDX plywood painted flat black. Corrugated FRP was mounted over the absorber leaving a six inch space between absorber and the glazing.

Air entering the west end through a 3 foot by 3 foot louvered duct was pulled through the collector by a 24 inch diameter 9.2 HP axial flow fan attached to the drying bin. The solar heated air was ducted to the bin through a 24 inch diameter, uninsulated, buried, concrete duct. Photo G1 shows the air vent on the west end of the solar collector. Shutters placed along the top edge of the solar collector could be opened during summer months to allow natural ventilation preventing excessively high stagnation temperatures. The top vent above the louvered vent was kept open during grain drying operation.

The collector was constructed for \$2.29 per square foot making this collector the least costly one of the ten demonstrations.

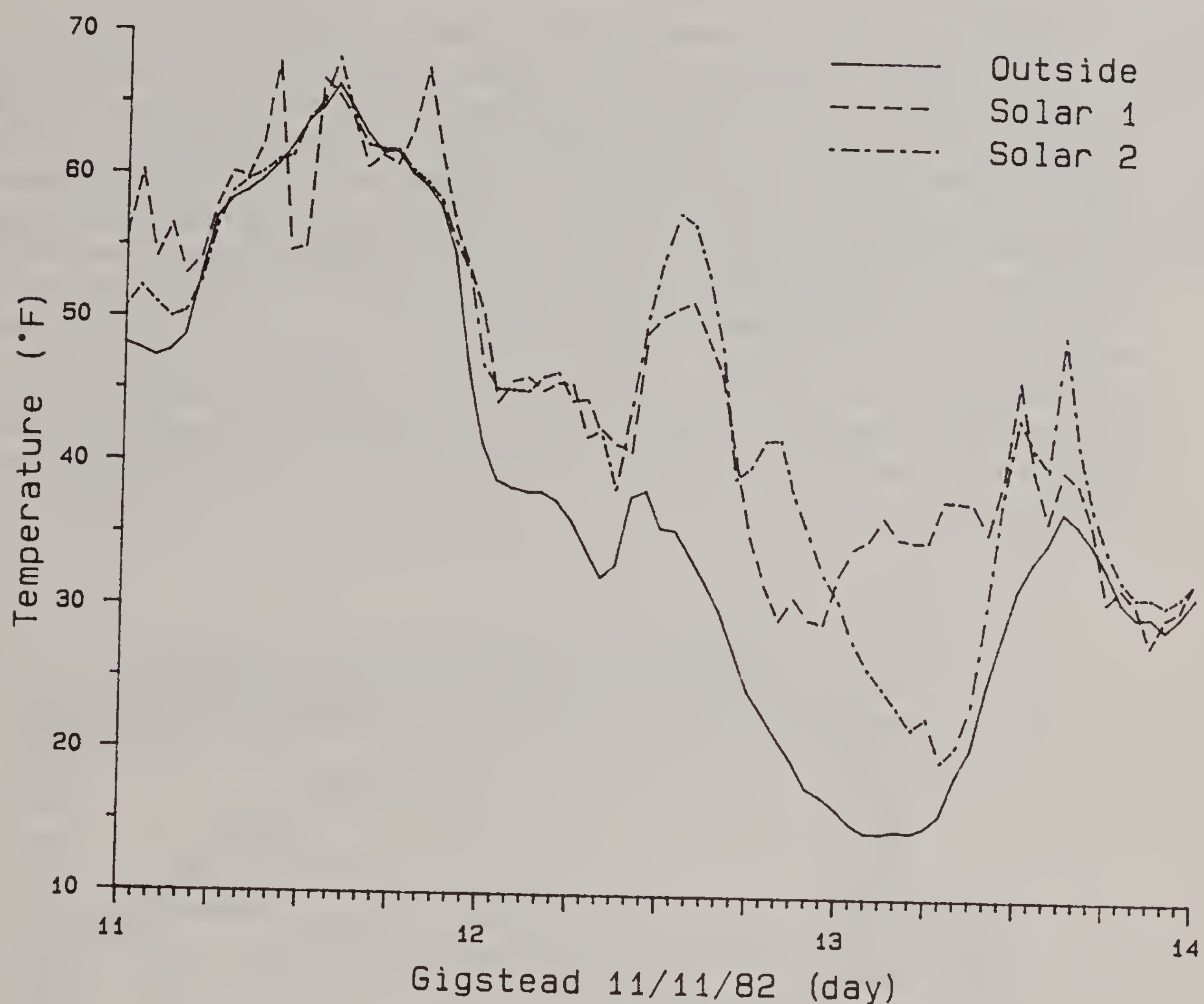


Figure G1

Measured Performance:

The collector was used 25 days for grain drying the period from November 4 through December 9. An equivalent of 0.12 gallons of LPG of energy per square foot of collector was delivered to the drying bin. Airflow through the collector was 3.5 cfm per square foot of collector. At this airflow, the peak output of the collector was 89.5 Btu/ft^2-hr. Clear day solar radiation available on a vertical surface during that period was 258 Btu/ft^2-hr. Peak efficiency could therefore be estimated as:

$$\text{Eff} = \frac{\text{collected solar energy}}{\text{available solar energy}} \times 100\%$$

or

$$Eff = \frac{89.5 \text{ Btu/hr-ft}^2}{258 \text{ Btu/hr-ft}^2} \times 100\% = 35\%$$

Figure G1 show temperature rises through the collector during November 11 through November 13. Solar 1 is the air temperature at the bin and Solar 2 is the air temperature at the collector. The three days presented in Figure G1 cover a wide range of ambient temperatures. Mean ambient temperature for the three day period was 38.1°F. Mean temperature at the solar collector was 44.9°F while the mean air temperature delivered to the drying bin through the concrete duct was 45.9°F. One can note a slight energy gain (2%) as the solar heated air travels through the uninsulated buried concrete duct. Figure G2 present earth temperatures at Topeka, Kansas at various depths along with daily average temperatures. Earth temperatures at five foot depth remain higher than ambient averages from about the middle of September on through the fall drying season, hence, the reason for not insulating the buried duct.

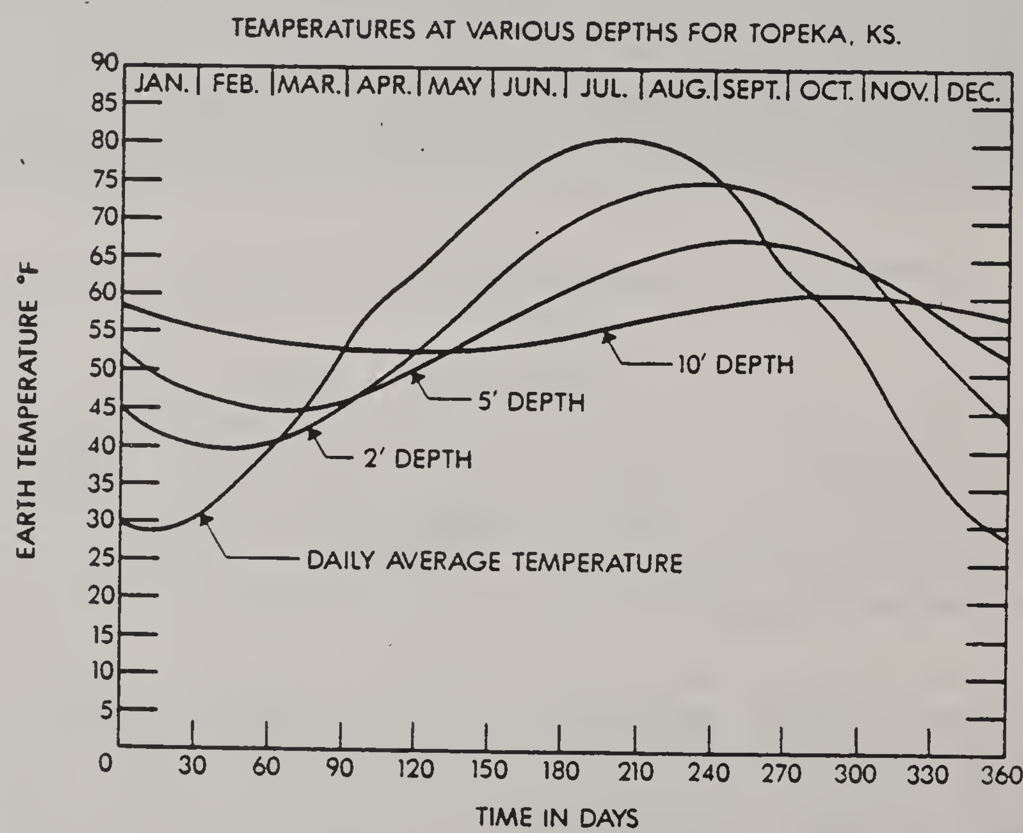


Figure G2

Grain Drying Operation:

The grain bin was filled with 6,400 bushels of grain sorghum on November 4 at a moisture content of 20%. The grain sorghum was dried to 15% by December 20, 1982. About 21,000 pounds of water were removed

during the drying period. Energy provided from the collector provided 35% of the energy to evaporate the water.

Economic Feasability:

Since the collector's alternate use is for heating the machine shed when not being used for grain drying, only 25% of the collector cost was apportioned to the economic feasability analysis. Based on this proportion, the collector had an inflation-adjusted after-tax annual return of 18% on invested capital. This rate of return is probably satisfactory to most producers. Possibly a larger portion of the collector cost should have been included in the economic analysis since the buried duct is exclusively used for the grain drying. Even if 50% of the cost would have been used, the analysis still gave a positive rate of return.

Henke Solar Demonstration

Arnold Henke
Rural Route
Cuba, KS 66940

Photo H1

Solar Collector:

The Henke collector was a commercially available collector that was purchased through a local dealer. The collector was manufactured by Solar Search Corporation, Box 118, Cissna Park, Illinois 60924.

Photo H1 shows a view of the collector as it was used for grain drying. The collector was mounted on a trailer to make it portable. Photo H2 is a end view of the collector showing the air intake which is used for grain drying. The collector tilt with horizontal is 64°.

It is a suspended flat plate collector with Filon 856 single layer glazing and an aluminum absorber painted with a flat black paint. This collector is similar to the Davis collector. It was tested by Wyle Laboratories and has an efficiency of 55% when the input temperature to the solar collector is ambient. (See Figure D1)

The collector measuring 8 feet x 28 feet with a surface area of 224 square feet was purchased in November of 1981 at a cost of $5,618.65. Total cost per square foot of collector surface area was $25.08 per square foot. Since the collector is used to provide additional heat to

Photo H2

the residence as well as dry grain, 25% of the total cost was apportioned to grain drying economic analysis.

Measured Performance:

Although the Henke collector was used during two grain drying seasons for this demonstration project, we collected data only during the 1982 season. Airflow rate through the collector was 3.5 cfm per square foot of collector. Energy was collected for grain drying during 16 days for two batches of grain sorghum during November and December. During that period, an equivalent of 0.07 gallons of LPG per square foot of collector were delivered to the drying bin. Figure H1 is a plot of hourly temperatures on November 6, 1982 showing ambient and solar heated air temperature.

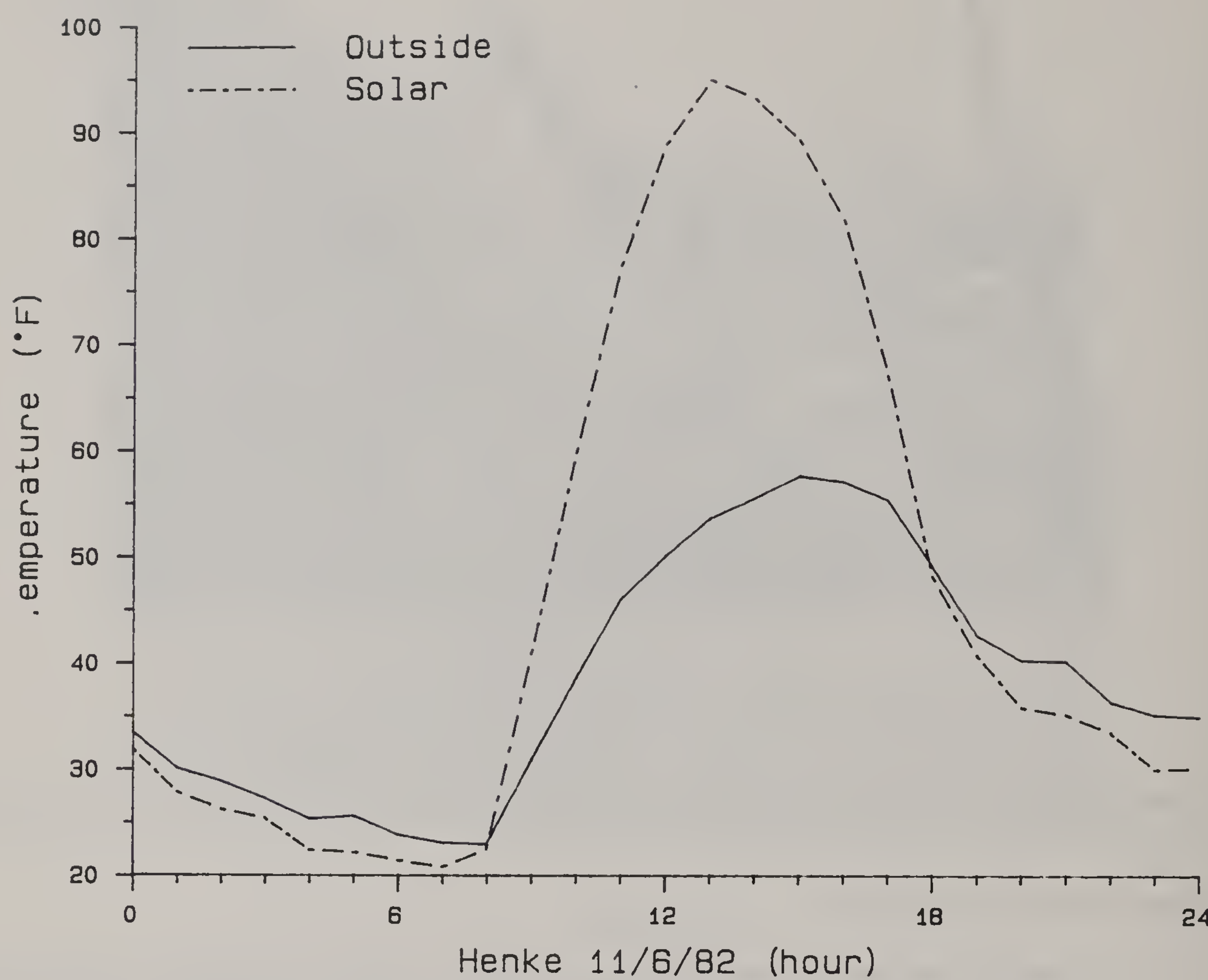


Figure H1

We believe this plot to be representative of a clear day. Measured maximum output was 138 Btu/hr-ft^2 for that day. Insolation values from tables indicate there was approximately 300 Btu/hr-ft^2 of solar energy available to the solar collector. Using the equation for efficiency:

$$\text{Eff} = \frac{\text{collected solar energy}}{\text{available solar energy}} \times 100\%$$

or

$$\text{Eff} = \frac{138\ \text{Btu/hr-ft}^2}{300\ \text{Btu/hr-ft}^2} \times 100\% = 46\%$$

This agrees reasonably well with the laboratory tested efficiency.

Grain Drying Operation:

Henke dried two batches of grain sorghum during the fall of 1982. The first 2900 bushels were dried from 18.8% to 13.0% moisture content.

The second 2700 bushel batch was dried from 17.1% to 13.0% moisture content. The total amount of water removed was 17,952 pounds. Energy delivered to the grain bin by the solar collector was 1.4 million Btu or enough energy to remove 936 pounds of water from the grain. Energy from the collector amounted to slightly over 5% of the total energy for moisture evaporation from the grain.

The drying bin was equipped with a 24 inch diameter 5 HP axial flow fan. Solar heated air was delivered to the bin through a 12 inch diameter uninsulated corrugated 18 foot long plastic duct. Ambient air was mixed with the solar heated air at the drying fan.

Economic Feasability:

Collector cost used in the economic analysis for grain drying was 25% of the total collector cost or $6.27 per square foot of collector. We felt this was a reasonable portion since its alternate use will be for heating the home. Considering the amount of energy collected for grain drying, the system had a negative rate of return as tested for the 1982 fall grain drying season. In order for the solar system to have a 10 year of inflation-adjusted after-tax payback, 0.47 gallons of LPG equivalent would need to be each season. This is nine times the amount of energy which was collected for the 1982 fall drying period.

Keesecker Solar Demonstration

Dale Keesecker
P.O. Box, Route 2
Washington, KS 66986

Solar Collector:

A solar wall developed by Kansas State University had previously been installed on the south facing side of a 44 stall farrowing building. Figure K1 shows the solar wall detail with the construction of the KSU solar wall described as follows. The solar wall was initially designed for preheating ventilation air for the farrowing house but was modified to facilitate its use also for grain drying.

A 24 foot diameter 9600 bushel bin with a full perforated floor was constructed northeast of the existing farrowing house. A 18 inch diameter uninsulated buried plastic duct was installed between the solar collector plenum and the drying fan at the bin. The duct was approximately 50 feet long. Photo K1 shows the connection to the solar wall plenum and to the drying fan. The collector pictured in Photo K2 had a exposed area of 840 square feet. The solar wall was constructed in two 60 foot sections each 7 foot high. Both solar wall plenums were connected at the center of the building by a plywood constructed duct. The cost of the collector-storage wall was $4,652 or $8.40 per square foot of collector area of which 25% of this cost was allocated to grain drying for the economic analysis.

Construction of the KSU Solar Collector:

1. Construction of the collector begins with a concrete foundation two feet wide and extending downward to below frost depth. Reinforcing steel should extend horizontally from the foundation to attach a reflecting sidewalk. The overhang on the south side of the building should extend at least 30 inches from the interior wall. The collector is 24 inches wide, which leaves a minimum of a six-inch overhang for icicle problems and summer shading. A hole in the south interior wall is utilized for duct work, which will admit air from the collector to the building. During grain drying, this hole is closed.

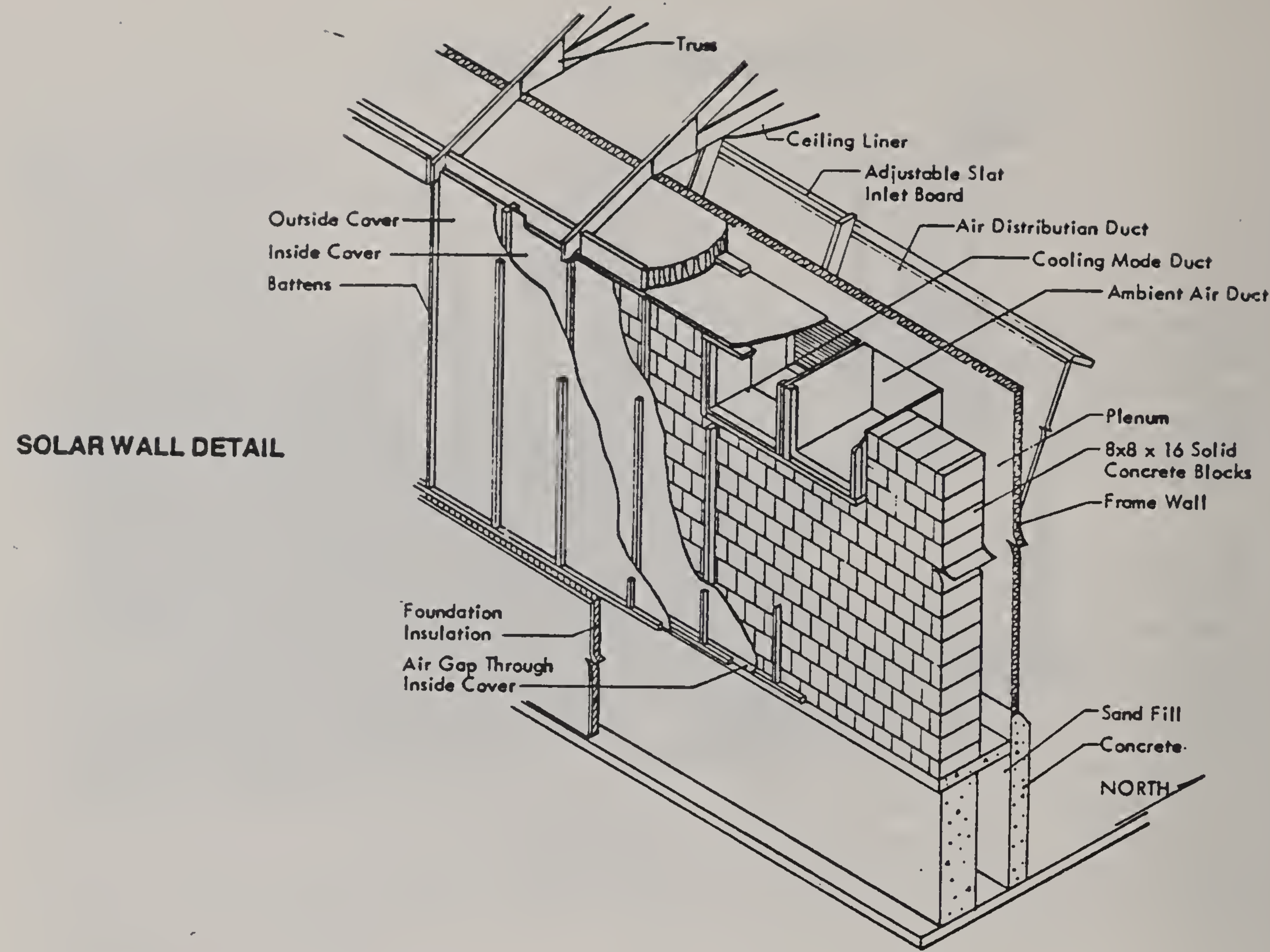
2. Clay tile, extending from the foundation, is utilized in pumping animal waste from the building if a pit manure storage system is used. Solid concrete blocks are then stacked on top of the foundation. Blocks are normally 16 inches high. All blocks are placed with the 16 inch dimension perpendicular to the foundation. The blocks are stacked leaving a 6-inch air space between the building wall and the back of the blocks. The foundation should be insulated with 1 inch of styrofoam and covered with cement asbestos board.

3. The blocks are stacked with four dabs of construction adhesive between the horizontal joints to hold them in place. A 3/16-inch

Photo K1

Photo K2

wide vertical crack is left between each block. This 3/16-inch wide slot is used for incoming air so that heat may be exchanged between the block and the air flow through the 3/16-inch wide slot.


Truss
Ceiling Liner
Adjustable Slat Inlet Board
Air Distributian Duct
Cooling Mode Duct
Ambient Air Duct
Outside Cover
Inside Cover
Battens
SOLAR WALL DETAIL
Plenum
8x8 x 16 Solid Concrete Blocks
Frame Wall
Foundation Insulation
Air Gap Through Inside Cover
Sand Fill
Concrete
NORTH

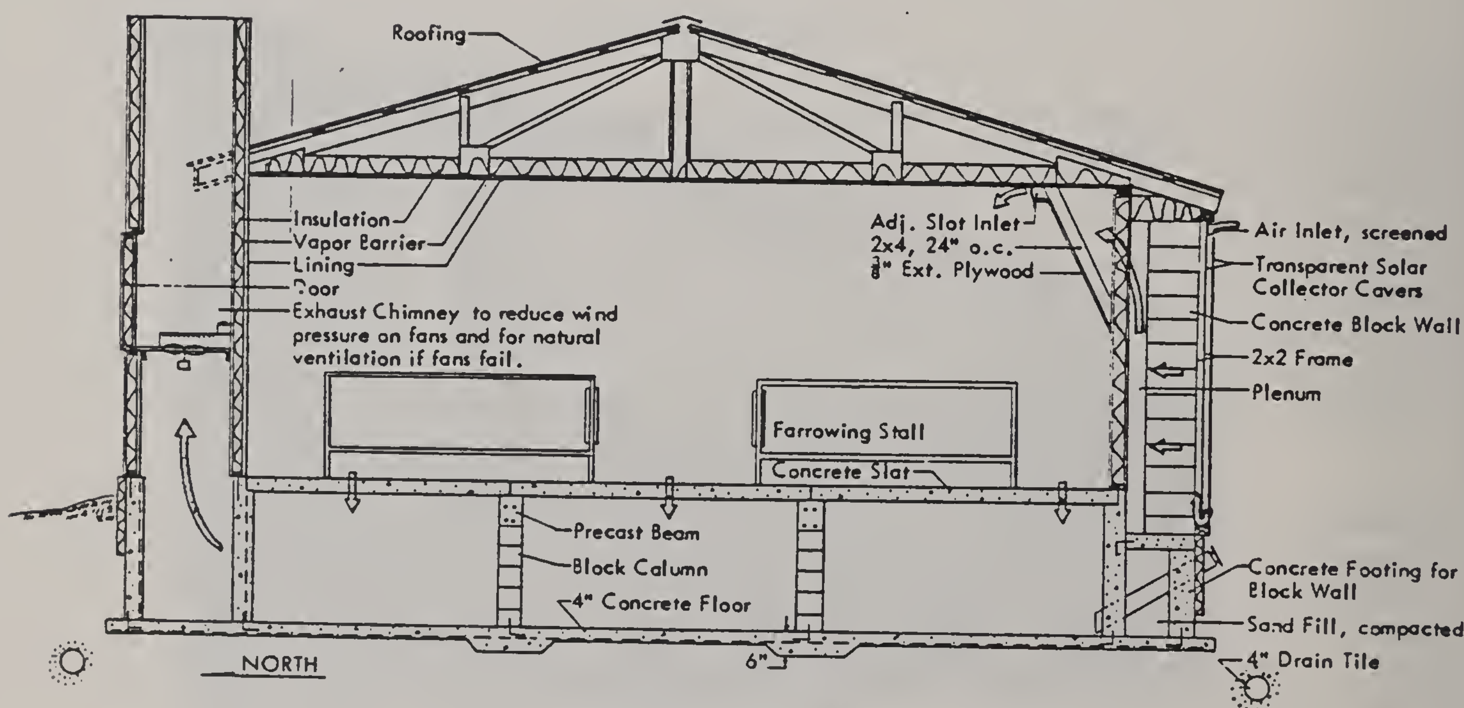

Roofing
Insulation
Vapor Barrier
Lining
Door
Exhaust Chimney to reduce wind pressure on fans and for natural ventilation if fans fail.
Adj. Slot Inlet
2x4, 24" o.c.
3/8" Ext. Plywood
Air Inlet, screened
Transparent Solar Collector Covers
Concrete Block Wall
2x2 Frame
Plenum
Farrowing Stall
Concrete Slat
Precast Beam
Block Column
4" Concrete Floor
Concrete Footing for Block Wall
Sand Fill, compacted
4" Drain Tile
NORTH
6"
CROSS SECTION

Figure K1

4. The blocks are then painted with a petroleum-based flat black paint. Normally, two coats are required to get a good surface for absorbing incoming radiation.

5. At this stage of construction, the top of the block wall is sealed and insulated to reduce heat loss through the roof. Normal height of the block wall is about eight feet.

6. White pine wood strips (3/4 inch by 1 1/2 inch wide) are then nailed and glued to the black face. These vertical wood strips are painted white and spaced 2 to 2 1/2 feet apart. White-painted, (1 3/4 inch x 1 1/2 inch) wood strips are mounted horizontally along the top and bottom of the vertical strips to complete the mounting frame for the first transparent cover. The transparent cover is attached with flathead wood screws. If fiberglass is used, holes should be drilled oversized to allow for thermal expansion and contraction. A two-inch slot at the bottom of the cover is used to admit air to the blocks.

7. An additional 1 1/2-inch wood frame is applied directly over the inner wood frame and transparent cover so that a second transparent cover can be applied. This outer cover has an opening at the top which is screened. Wooden battens are fastened over the outer cover to secure it. Wood screws should be used.

8. Air enters the collector through the screen inlet at the top of the outer cover. This inlet is sized to distribute air along the length of the collector with about a 0.05" H_2O pressure drop. The air then travels downward between the two covers to the bottom of the inner sheet, where it then turns a 180 degree direction to flow through the vertical cracks in the concrete block wall. The air travels through the block wall and into the plenum. The vertical flow of air between the two transparent sheets reduces the heat loss from the concrete blocks. Snow cover or reflector panels on the ground significantly increase the incoming solar radiation.

9. Chimneys on the north side of the building enclose exhaust fans which power the ventilation system year round. Air is exhausted vertically from the building to eliminate the strong wind influence in Kansas. During normal winter operation, the fans are the only moving part of the collector, which decreases electrical operation costs of the system.

10. Care must be taken during construction to insure that all joints are as air-tight as possible to guarantee that ventilating air comes through the concrete wall.

11. Construction details are given in plan #81902 available from Extension Agricultural Engineering, Room 237 Seaton Hall, Manhattan, Kansas 66506.

Measured Performance:

The data logger installed October 25, 1982 obtained usable data from October 25 through November 6, with the exception of October 28 through November 2 and November 8 through November 12. The remainder of the data was too irractic to be of any value. We predicted the energy saved over the 46 day drying period from the 12 days of good data we obtained. We estimated that an energy equivalent of 0.47 gallons of LPG per square foot were delivered to the drying bin. Airflow through the collector was 3000 cfm which was 3.6 cfm per square foot of collector. Earlier tests of the KSU solar wall indicate collection efficiency to be between 60 and 62 percent for the airflow rate we had. Measured energy at both the solar wall plenum and the drying fan for the 12 days of good data indicate a 12% energy gain through the buried duct.

Grain Drying Operation:

The bin was filled with 9600 bushels of grain sorghum by October 25 with a moisture content of 19%. The 3 HP axial flow drying fan was run continuously through December 9 at which time the moisture content was down to 14 1/2%. The amount of moisture removed from the grain was 28,295 pounds. Based on 1500 Btu of energy to remove one pound of water about 42 million Btu would be required. About 33 million Btu were provided by the collector.

Economic Feasability:

The inflation-adjusted after-tax return on this collector was 30%. Cost of the collector allotted to grain drying was 25% of the total costs or $1.39 per square foot of collector. The collector has already proven to be economically attractive for tempering ventilation air for the farrowing house using 100% of the collector cost in the analysis. In a KSU study of Solar Heating of On-Farm Livestock Shelters a 6% annual rate of return was predicted.

Parmley Solar Demonstration

William Parmley
Rural Route 1
LeRoy, KS 66857

Photo P1

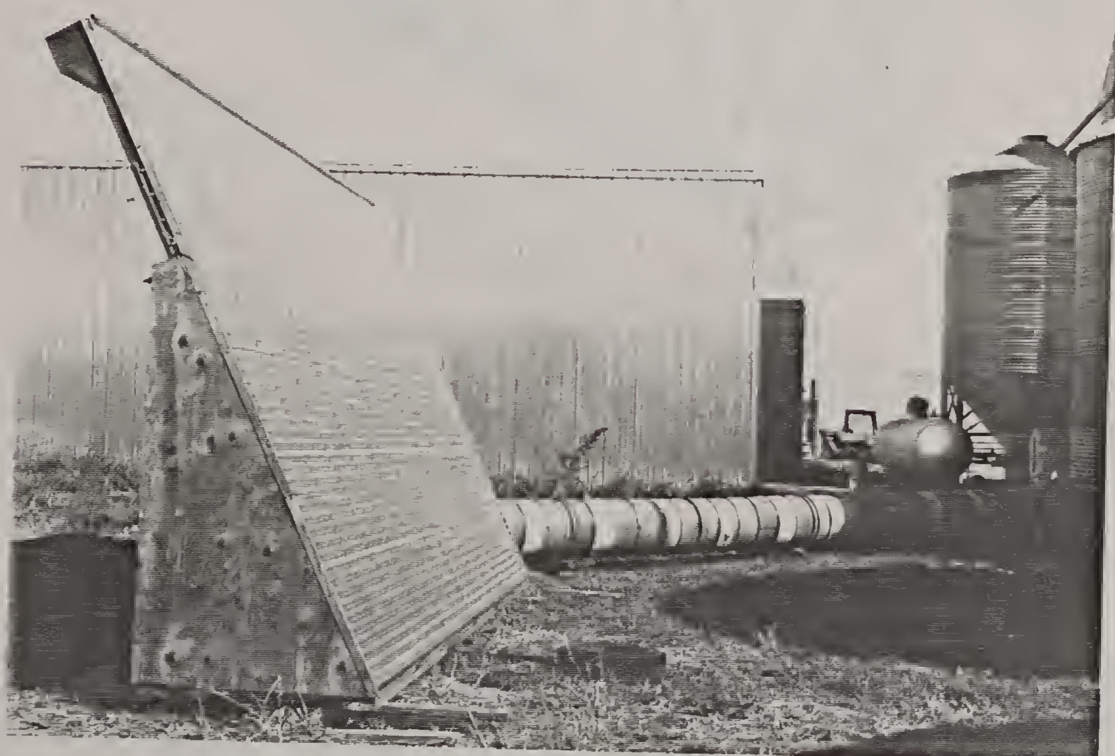


Photo P2

Solar Collector:

A portable solar collector developed by the University of Illinois was constructed for the Parmley demonstration. Figure P1 show detail of the construction. The collector had a surface area of 288 square feet and was built at a cost of $3.28 per square foot of collector. Air was ducted from the collector to the drying bin through a 22 inch diameter uninsulated metal duct about 60 foot long was constructed from 55 gallon drums with their ends cut out. Photo P1 and P2 show front view and end view of the collectors. Since the collector was used exclusively for grain drying, 100% of the cost was apportioned to the economic analysis.

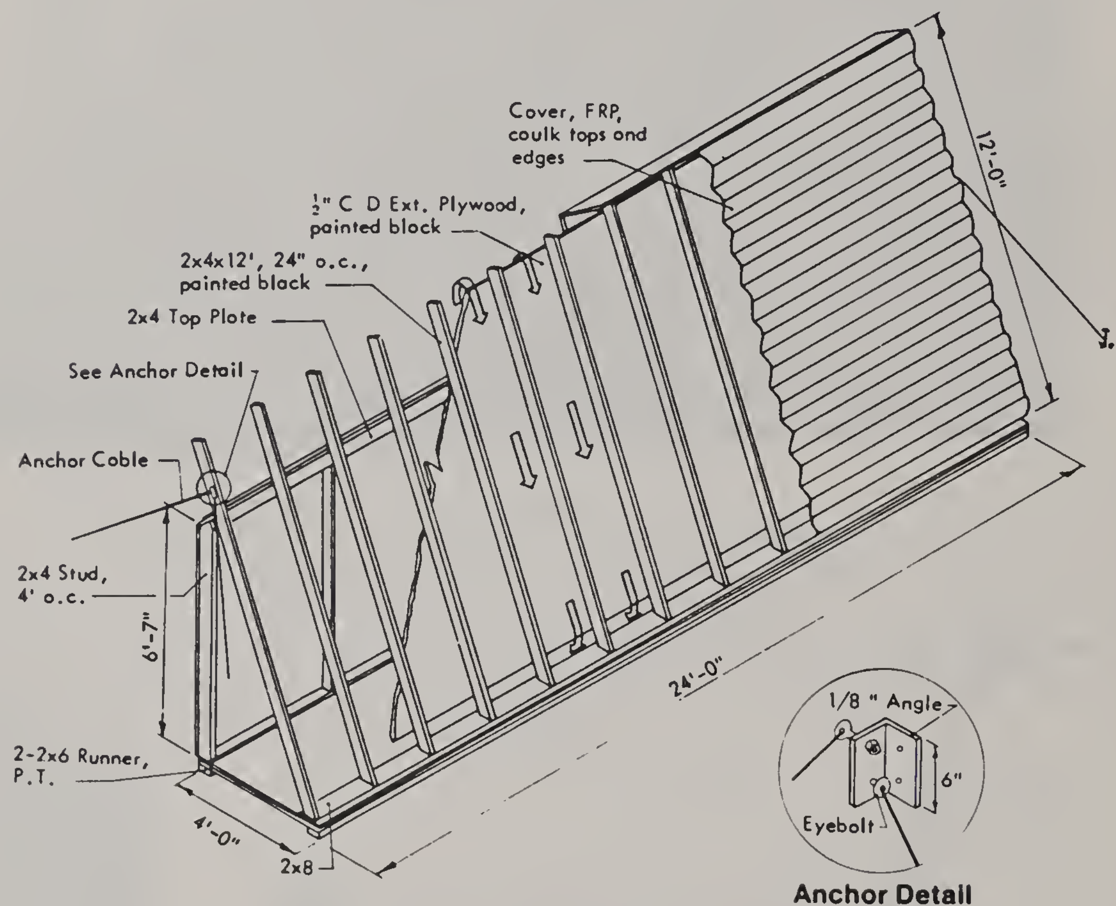


Figure P1

Measured Performance:

Thermocouples were used to record temperatures through the collector and temperatures delivered at the bin as well as ambient temperatures. Reliable data was obtained from November 3, 1982 through October 13, 1982. These 21 days were used to predict the performance during the 80 day 1982 fall drying period. Airflow through the collector was 5324 cfm which was 18.5 cfm per square foot of collector surface. With this airflow rate a total of 43,576 Btu per square foot of collector was

delivered to the drying bin. This is equivalent to 0.25 gallons of LPG per square foot of collector. Figure P2 is a plot of ambient and solar heated air temperatures.

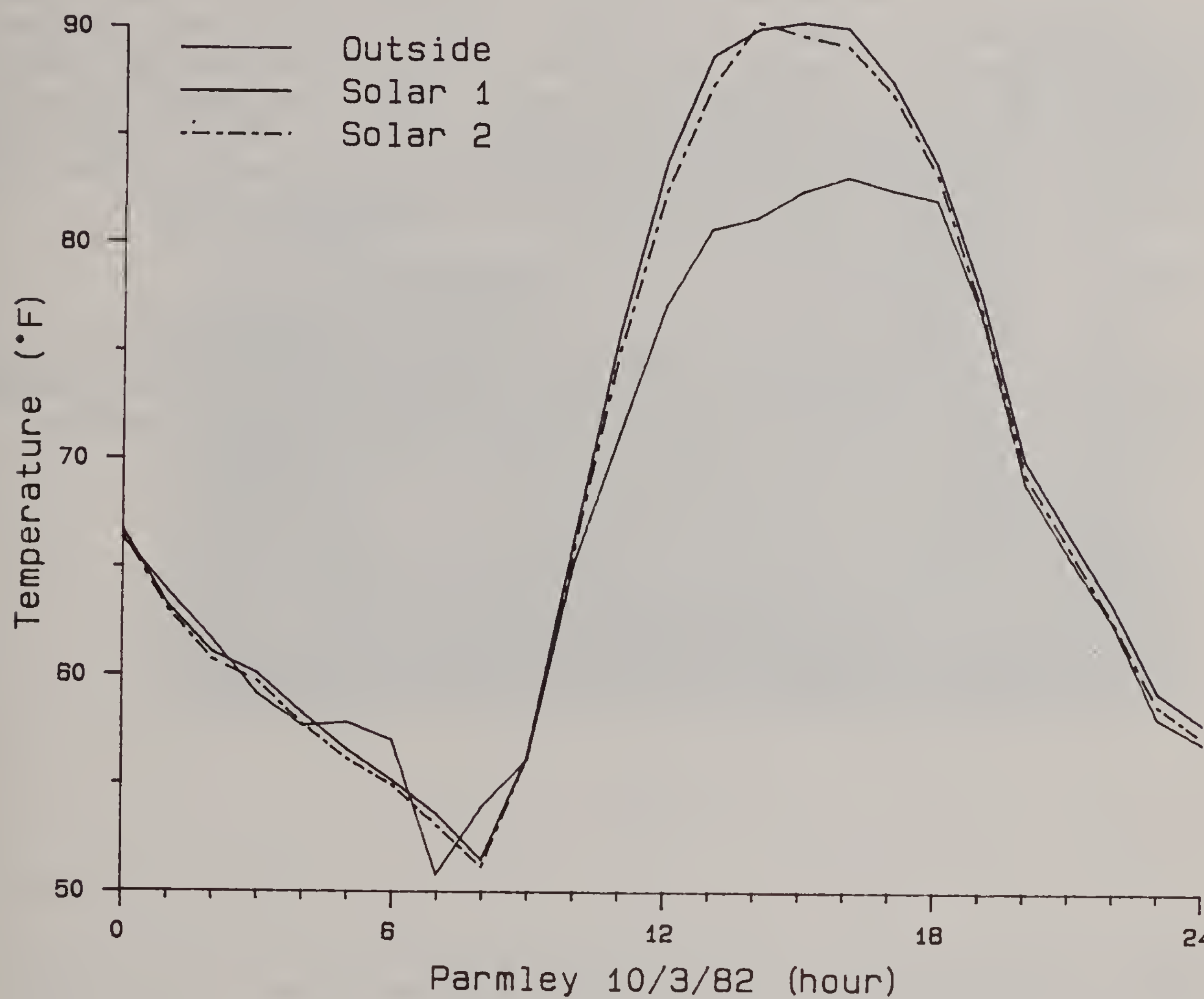


Figure P2

Solar 1 is the air temperature at the outlet of the collector. Solar 2 is air temperature delivered to the drying bin. The shape of this curve would most likely be representative of a day with clear day radiation. The peak efficiency that day can be determined by:

$$\text{Eff} = \frac{\text{collected solar energy}}{\text{available solar energy}} \times 100\%$$

Where collected solar energy was measured to be 177 Btu/hr-ft^2 and available solar energy (from tables) was about 300 Btu/hr-ft^2. Therefore, our estimated efficiency would be:

$$\text{Eff} = \frac{177\ \text{Btu/hr-ft}^2}{300\ \text{Btu/hr-ft}^2} \times 100\% = 59\%$$

Overall loss through the uninsulated duct was 15% for the 21 days during which we had reliable data.

Grain Drying Operation:

The solar collector was used to dry 6500 bushels of corn from 20% to 14% moisture content in 35 days. The duct was then directed to another drying bin in which 6500 bushels of grain sorghum was dried from 19.8% to 14% moisture content in 45 days. The total amount of moisture removed from both bins of grain was 49,944 pounds. The energy required to remove this amount of moisture would be 75 million Btu. The collector provided 10 million Btu or about 13% of the total energy.

Economic Feasability:

Since the collector was used exclusively for grain drying all of the collector cost was used in the economic analysis. The collector provided a 11% inflation-adjusted after-tax annual rate of return.

Runft Solar Demonstration

Donald Runft
Rural Route 1
Scandia, KS 66966

Photo R1

Solar Collector:

Four commercially available 4 foot x 10 foot solar panels were mounted on a wood constructed frame at an angle of 60° with horizontal. The panels were manufactured by LPC, Inc. of New Richland, Minnesota 56072. The panels are double glazed with Calwal Sunlite 2-A and have a 0.016 solar black painted steel V-shaped suspended absorber plate. They are insulated on the sides and back with Celotex to a R-4. Figures R1 and R2 show a side view and front view of the construction detail. Figure R3 is a isometric rear view showing how the four collectors are manifolded together. A blower fan built into the unit circulated 550 cfm of air through the collector panels. With the collector attached to the drying bin, the airflow rate through the collector was 818 cfm. The collector unit was mounted on a salvaged mobile home trailer frame as shown in Photo R1.

The collector was built at a cost of $4,956.88 which is $30.98 per square foot of collector. Of that total cost, 25% was apportioned to grain drying. The solar collector will be used to heat the home when grain drying is complete.

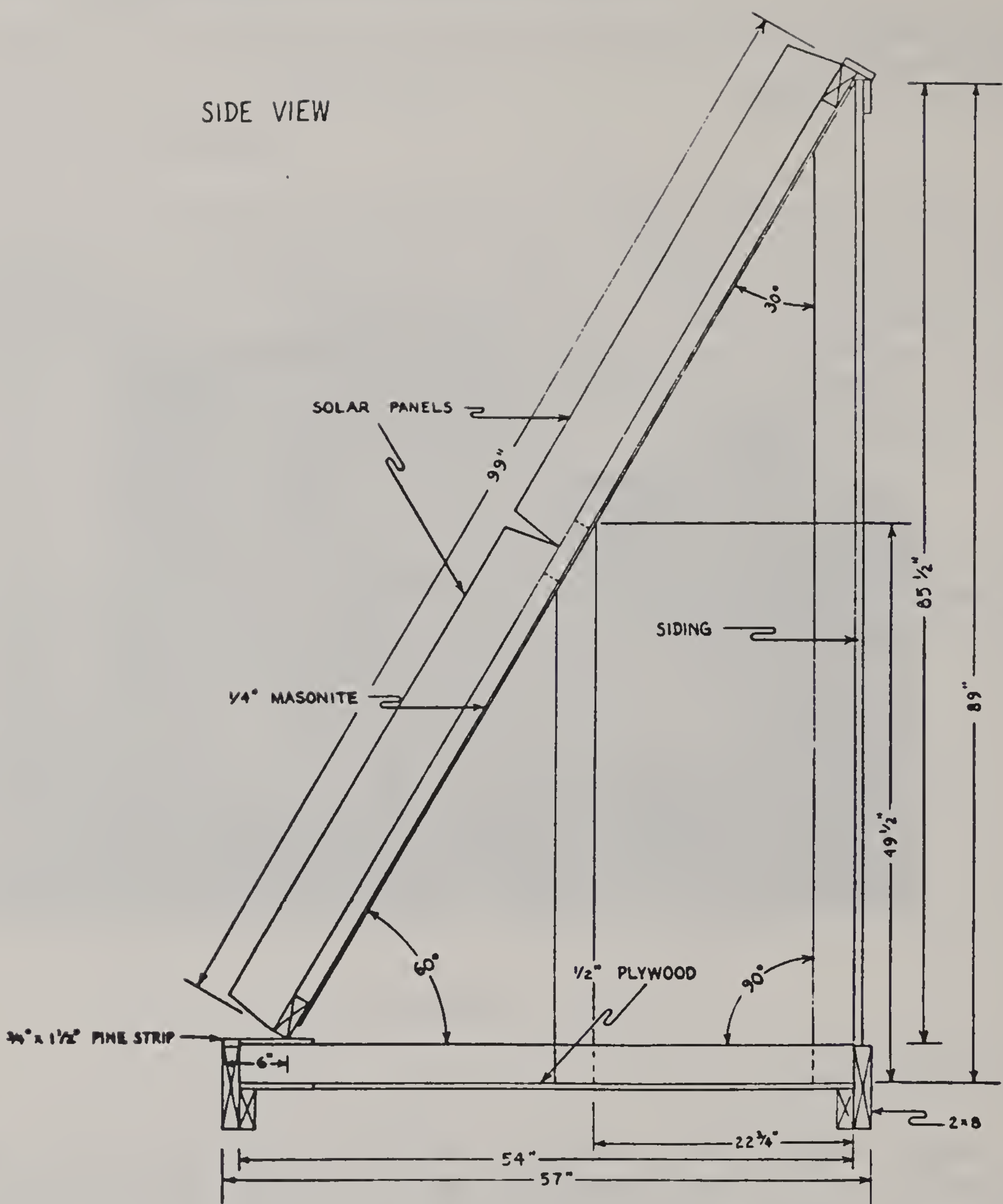


Figure R1

Measured Performance:

Solar heated air was transferred to the drying bin through a 10 inch diameter insulated flexible duct. The duct was approximately six feet long. The collector was used intermittently for 38 days and delivered an equivalent of 0.14 gallons of LPG of energy to the drying bin. Figure R4 is a plot of ambient and solar air temperatures on November 12, 1982. With the 818 cfm airflow rate, we measured for grain drying, the maximum calculated efficiency for that day would be well over 100% which of course is impossible. There was about a seven day period for which data typical of that were obtained. At one point, we found the duct had been disconnected from the drying fan. The solar

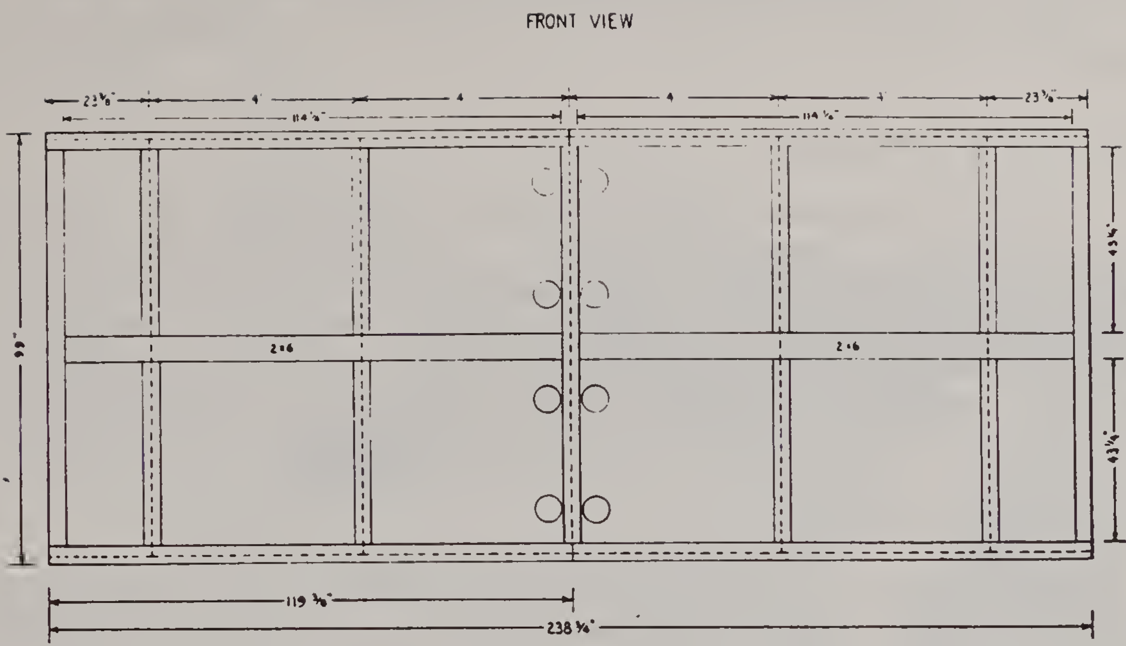


Figure R2

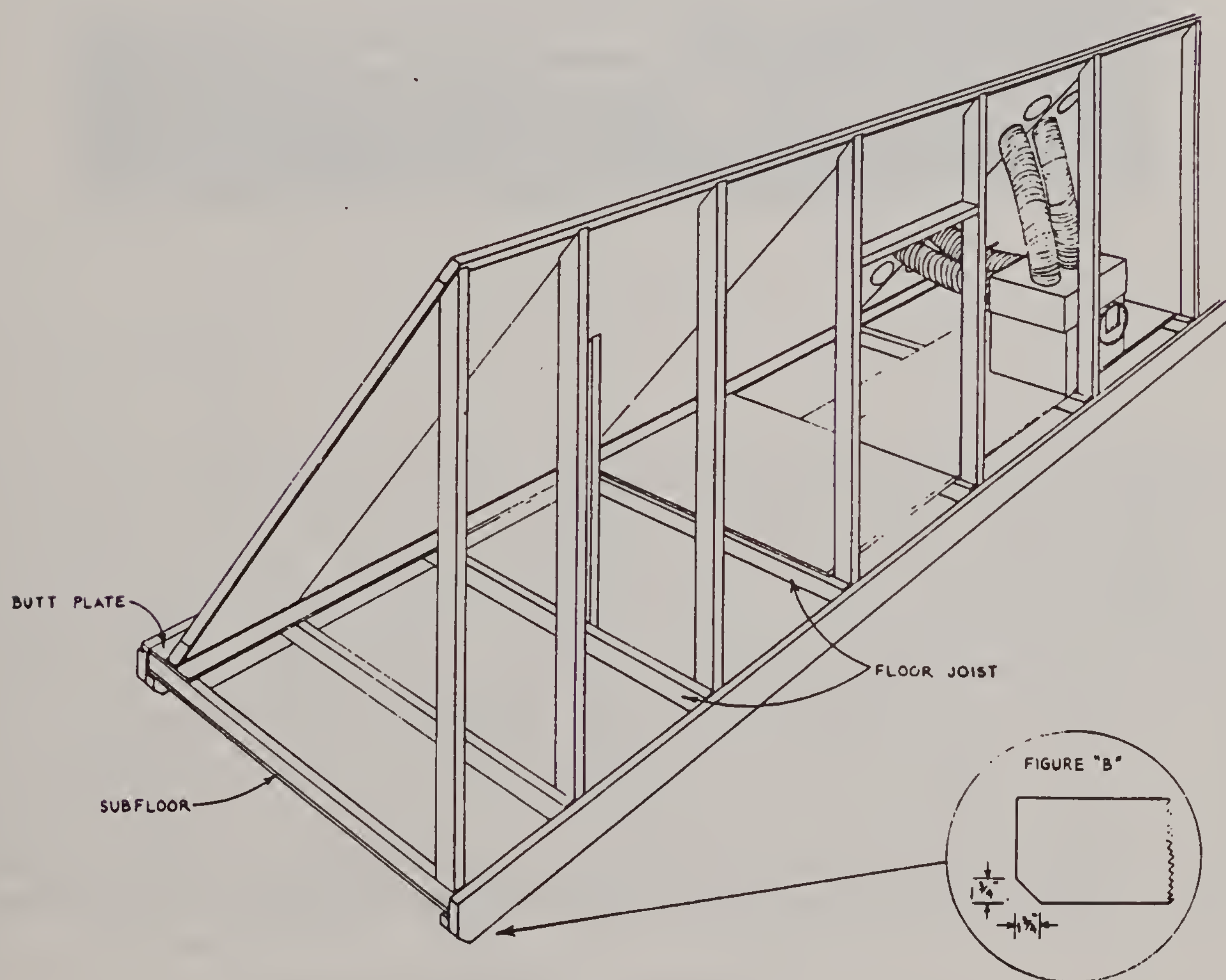


Figure R3

collector was located in an area where cattle could access the duct work. We speculate that on those seven days, the duct was not secure

properly to the drying bin fan and therefore airflow rate was considerably less than that which we measured. Efficiencies for small temperature rises through the collector as reported by the manufacturer are 68 to 70%.

Grain Drying Operation:

A 16 foot diameter grain bin was filled October 25, 1982 with 3,200 bushels of grain sorghum having a moisture content of 16.2%. By December 1, the moisture content measured at the top of the grain was 15.3%. Most likely, the average moisture content of the grain was considerably less. If we assume the average moisture content to be 14%, than 4,584 pounds of moisture were removed requiring 6.9 million Btu of energy. The solar collector provided 26% of the total energy.

Economic Feasability:

With the 25% of the collector cost used in our economic analysis. A negative rate of return on invested capital. For the collector to have a payback of ten years, it would need to save 0.60 gallons of LPG.

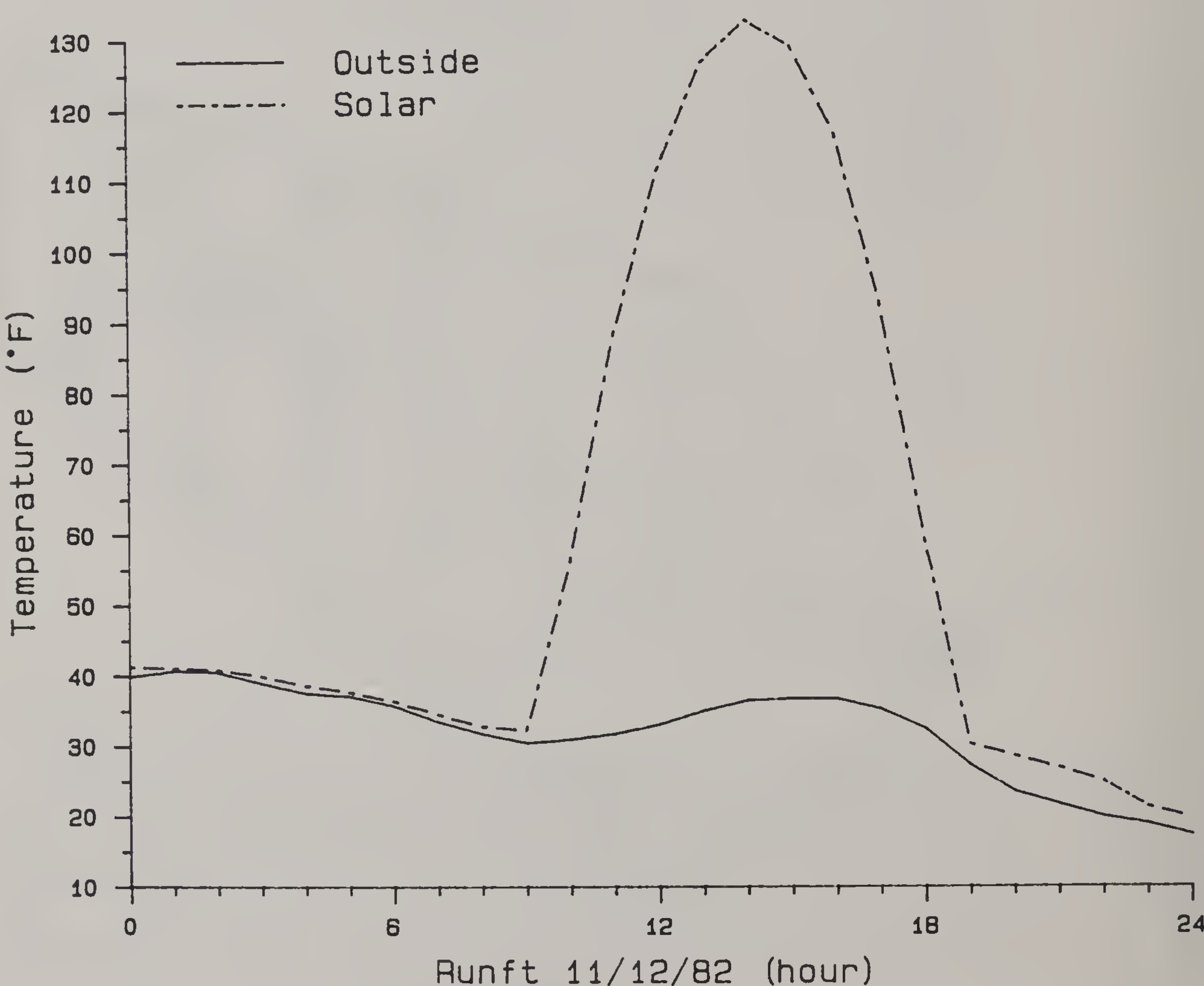


Figure R4

Schroeder Solar Demonstration

Irvin Schroeder
Rural Route 1
Moundridge, KS 67107

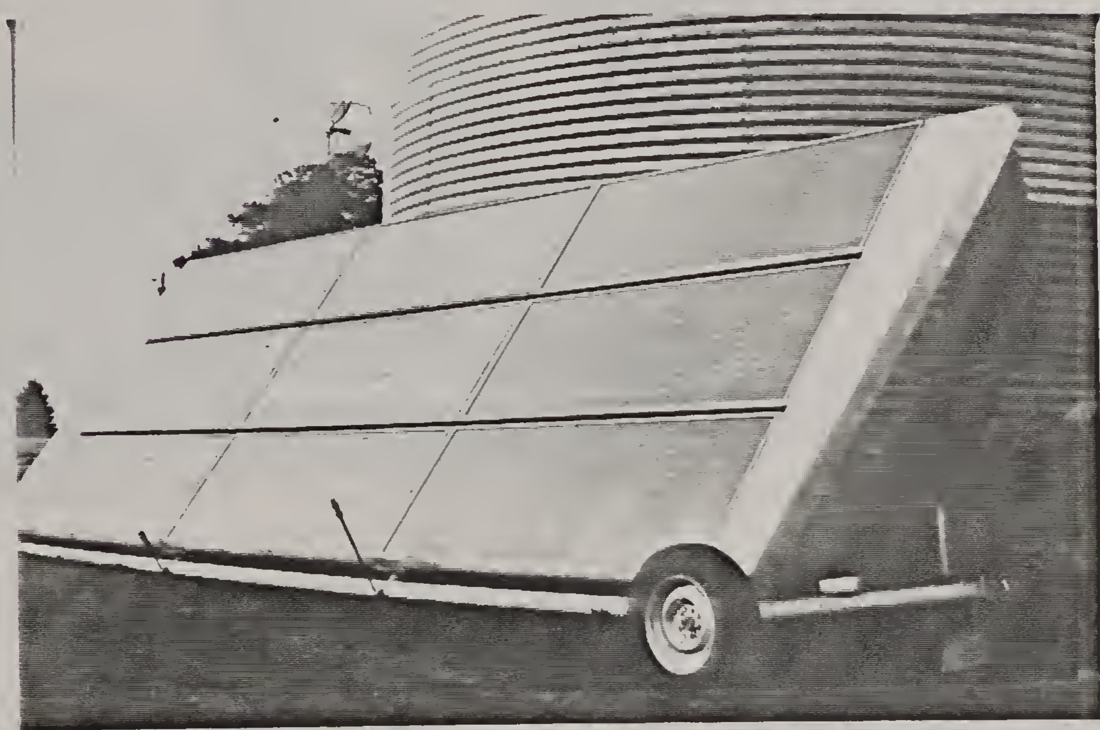


Photo S1

Solar Collector:

Nine 3 foot x 8 foot commercially available solar panels were mounted to a welded metal pipe constructed A-frame at a tilt of 55° from horizontal. The collector's glazing is 3/16 inches tempered (low-iron) glass covering an absorber plate made of flat black painted aluminum sheet with "V" folds. The collectors were made available from Sunflower Energy Works, Inc., Box 4, Lehigh, Kansas 67073. Airflow through the collector as viewed in Photo S1 is from left to right. Photo S2 shows the end view of the collector as it is being used to heat the home. Air, from the house, is drawn through a 12 inch diameter flexible insulated duct with a blower fan mounted on the collector. Air is circulated through the collector at a flow rate of 235 cfm which is slightly over 1 cfm per square foot of collector. The 198 square foot collector was built for $3,997.77 or $20.19 per square foot of collector area.

Photo S2

Measured Performance:

The data logger was installed October 7, 1982. For the most part, the data we obtained was not reliable enough to determine the seasonal performance. The manufacturer of the collector panel indicates that measurements show the collector efficiency to be: 80% - 145 ($\Delta T/I$). Where ΔT is the average temperature inside the collector minus the outside temperature (^{o}F) and I is the solar insolation in Btu/hr-ft^2 available to the collector. If we assume small ΔT's, such as the case for grain drying where higher airflow rates are used through the collector, then the efficiency approaches 80%.

Figure S2 is a plot of the solar heat air temperature and ambient temperature for October 18, 1982. Previous measurements of airflow with a hot wire anamometer indicated a rate of 400 cfm. Using the equation:

$$\text{Btu/hr-ft}^2 = 1.1 \times \Delta T \times \frac{\text{cfm}}{\text{ft}^2}$$

where ΔT from Figure S2 is $109^{o}F$ we get:

$$Q = \frac{1.1 \times 109 \times 400}{198} = 242 \text{ Btu/hr.ft}^2$$

Maximum solar insolation available to the collector would be about 310 Btu/hr-ft^2. This would result in an efficiency of 77%.

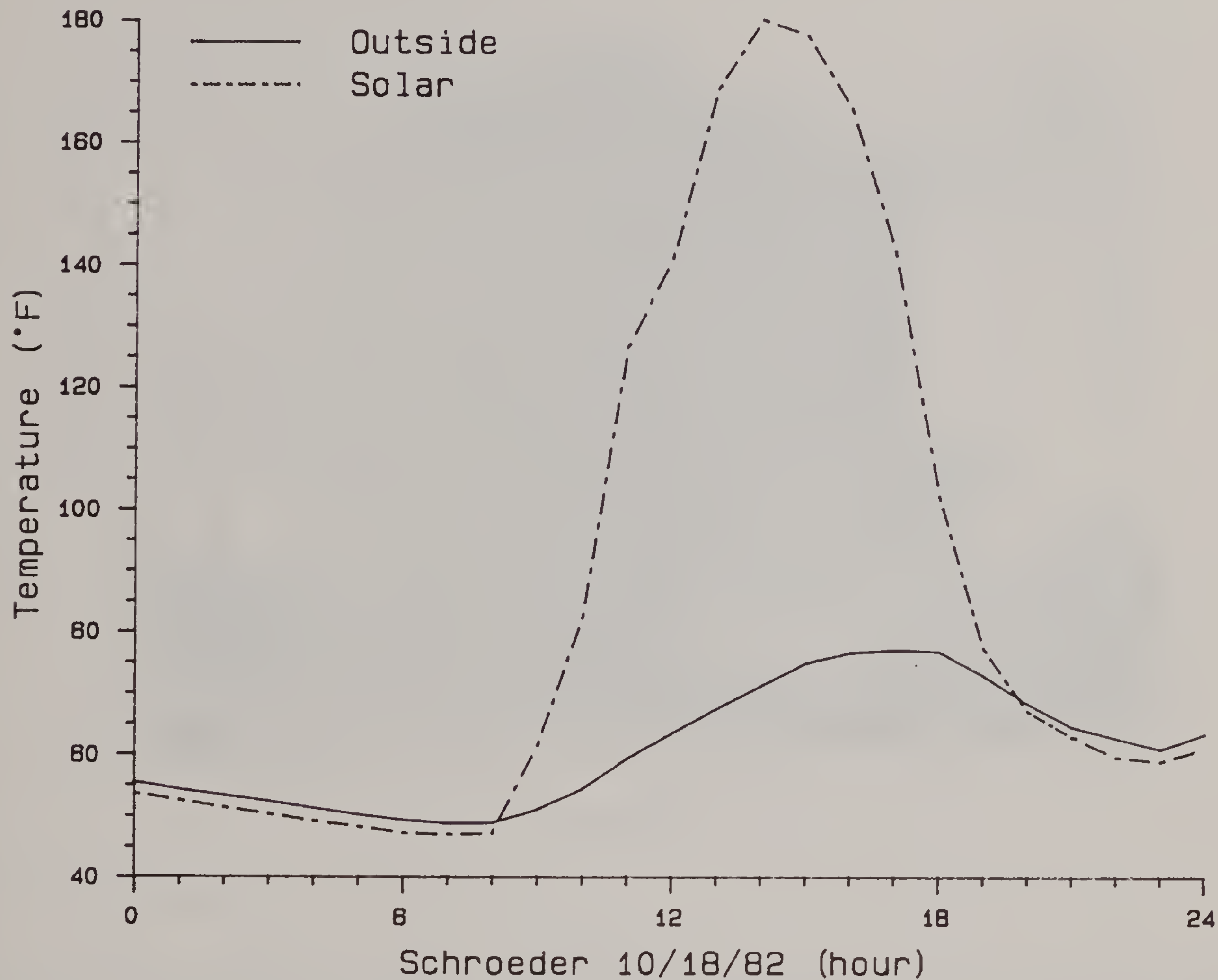


Figure S1

Since we did not have sufficient data to determine seasonal efficiency, average solar radiation data from Dodge City was used. With an estimated 50% overall collector efficiency during the 56 day drying period, fuel savings would have been 0.64 gallons of LPG per square foot of collector.

Grain Drying Operation:

The 24 foot diameter bin was filled between September 11-16 with 5600 bushels of grain sorghum with an average moisture content of 17%. By November 5, the grain had dried to 15.2%. LPG was used on October 11 and 12. The amount of moisture removed was 6,657 pounds. According to our estimates, the solar collector would have provided all the energy to remove it.

Economic Feasability:

Twenty-five percent of the collector cost was used in the economic analysis for grain drying because the collector was also used for heating the home. Considering the estimates we made, the collector would have a 7% inflation-adjusted after-tax annual rate of return.

A. Thompson Solar Demonstration

Andy Thompson
Rural Route
Courtland, KS 66939

Photo TA1

Solar Collector:

The A. Thompson collector, having a total area of 104 square feet, was constructed using four commercially available solar panels manufactured by Sun Wise, Incorporated, Box 6621, Great Falls, Montana 59406. Each panel has an aperature area of 26 square feet. It is a double-glazed, suspended, flat, plate collector. The outer and inner glazing are made of Lexan Sheet with the outer glazing being dome shaped. The manufacturer claims the dome shape improve the early morning and late afternoon performance. Photo TA1 shows the solar collector being used for grain drying. Air was delivered to the drying bin through an 8-inch diameter insulated corrugated plastic duct. Photo TA2 shows the duct as well as how the collector was manifolded together. The collector panels were mounted on a trailer for portability. When not drying grain, the collector was used to provide supplemental heat for the home.

Photo TA2

Collector cost was $5,965.53 which was $57.36 per square foot making this collector the most costly collector demonstrated in this project. Since the collector will be used to provide supplemental heat for the home when it is not being used for grain drying, only 25% of the collector cost was allotted for the economic feasability analysis.

Measured Performance:

Our data indicated the collector was used for grain drying during 15 days in November. The collector provided 0.10 gallons of LPG equivalent per square foot of collector. Airflow rate through the collector was 318 cfm which was 3 cfm per square foot of collector. Figure TA1 is a plot of hourly temperatures of ambient and solar heated air during November 26, 1982.

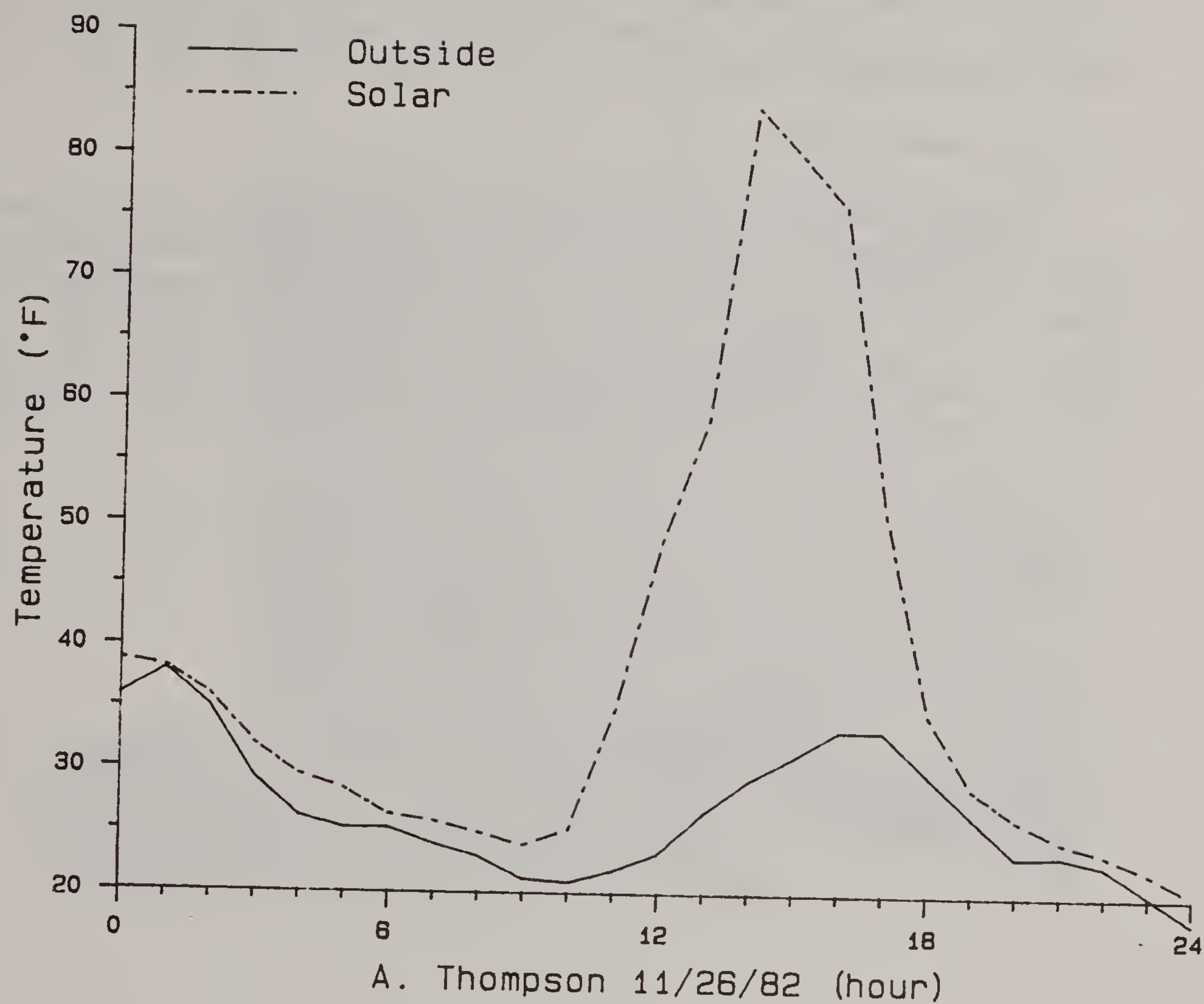


Figure TA1

We assummed this day to relatively clear. Peak energy output for that day was 179 Btu/hr-ft^2. From tables, we determined that 300 Btu/hr-ft^2 of solar insolation was available giving an efficiency of:

$$\text{eff} = \frac{\text{collected solar energy}}{\text{available solar energy}} \times 100\%$$

$$\text{eff} = \frac{179 \text{ Btu/hr-ft}^2}{300 \text{ Btu/hr-ft}^2} \times 100\% \quad = 60\%$$

Grain Drying Operation:

A 27 foot diameter grain bin was filled beginning November 1, 1982 with 13,000 bushels of corn at an average moisture content of 18.5%. The bin was equipped with a 24-inch diameter, 5 horsepower axial flow fan. Solar heated air was mixed with ambient air at the bin fan. Corn

was dried to 15.8% moisture content by November 24, 1982. A total of 23,344 pound of moisture was removed which would require about 35 million Btu of energy assuming 1,500 Btu of energy would remove one pound of water. The solar collector provided about 900,000 Btu or about 2 1/2% of the energy required to dry the grain.

Economic Feasability:

The high cost of this collector, even with only 25% of the cost or $14.34 per square foot of collector used in the economic analysis, produced a negative rate of return. In order for this collector to have a payback in 10 years, it would have to save 1.11 gallons of LPG per square foot of collector when used for grain drying. It is highly unlikely that this collector could save that much energy during normal grain drying periods in Kansas.

G. Thompson Solar Demonstration

Gerry Thompson
Rural Route
Courtland, KS 66939

Photo GT1

Solar Collector:

A home built collector was constructed from five commercially available solar panels manufactured by Continental Solar Systems, Inc., 5756 Larmy, Arvada, Colorado 80002. The five panels were mounted on a wood constructed frame at an angle of 40° with horizontal. The panels each having a collector area of 19.5 square feet are covered with two layers of 1/8 inch tempered glass with a 24 gauge steet absorber plate. The collector is insulated on the back to a R-factor of 10. Figure GT1 is a detail of the panel construction.

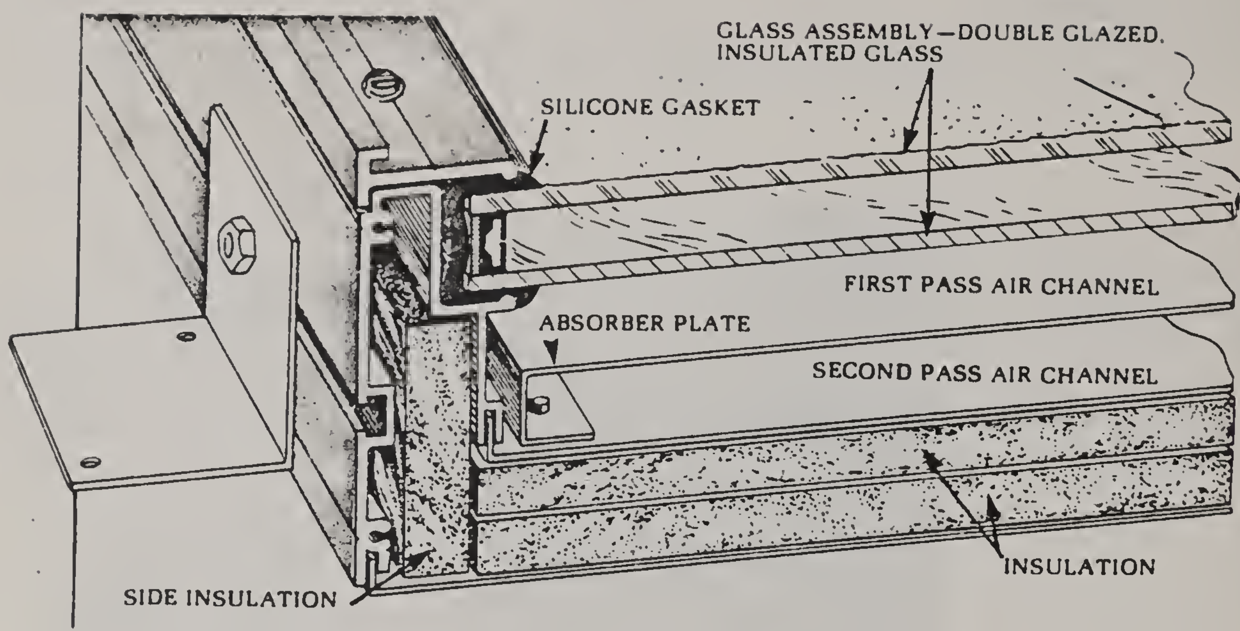


Figure GT1

Figures GT2 through GT6 show detail of the complete collector system. Photo GT1 pictures the collector positioned for grain drying use.

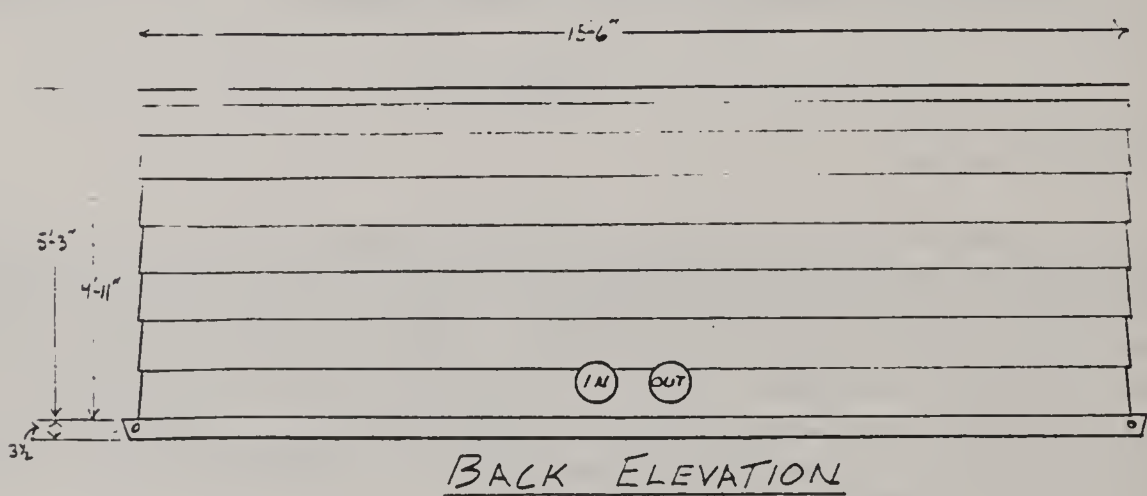


Figure GT2

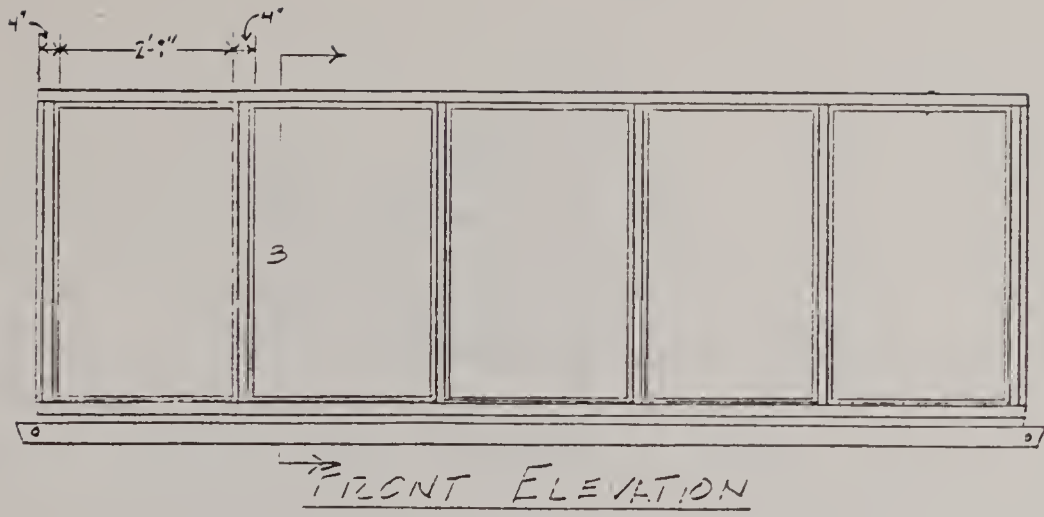


Figure GT3

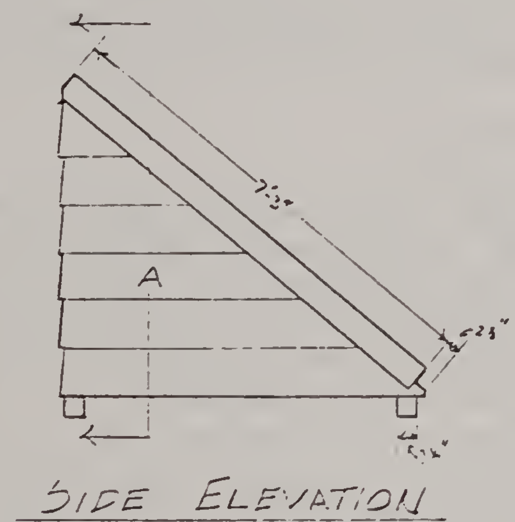


Figure GT4

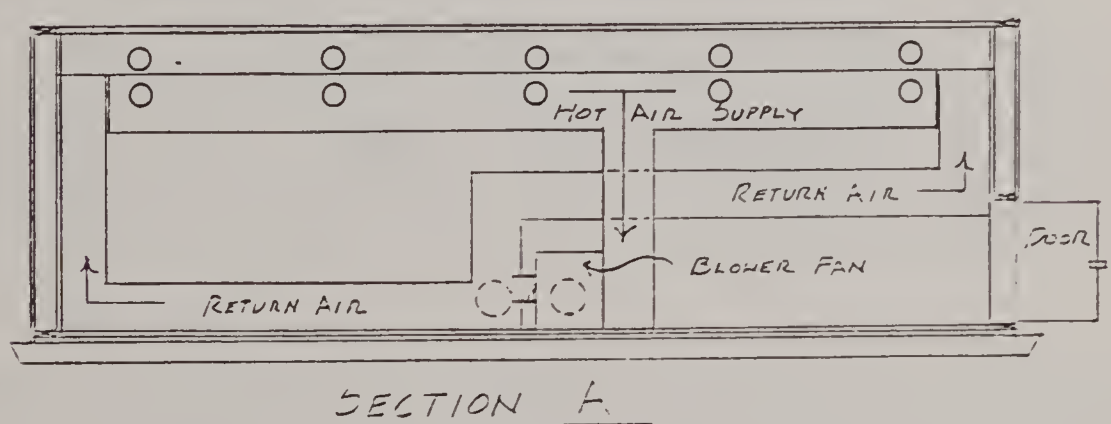
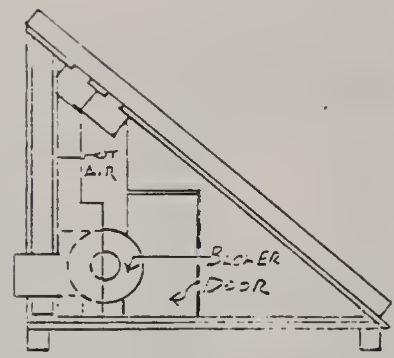


Figure GT5



SECTION B

Figure GT6

The total collector area was 98 square feet and was built at a cost of \$4,324.35 or a cost of \$44.13 per square foot of collector. This collector was the smallest collector demonstrated in this project.

Measured Performance:

The collector was used 27 days from October 20, 1982 through November 10, 1982 to supplement heated air to dry 3,400 bushels of corn. Airflow through the collector was 271 cfm or 2.8 cfm per square foot of collector. An equivalent of 0.25 gallons of LPG per square foot of collector was delivered to the drying bin through an 8 inch diameter insulated aluminum duct approximately 25 feet long. Figure GT7 shows a plot of hourly temperatures of ambient and solar heated air for November 2, 1982. The shape of this curve would most likely indicate clear day radiation. The maximum output was 156 Btu/hr.ft^2. From tables, available solar insolation was 310 Btu/hr-ft^2. Efficiency was calculated using the equation:

$$\text{eff} = \frac{\text{collected solar energy}}{\text{available solar energy}} \times 100\%$$

$$\text{eff} = \frac{156\text{Btu/hr-ft}^2}{310\text{Btu/hr-ft}^2} \times 100\% \quad = 50\%$$

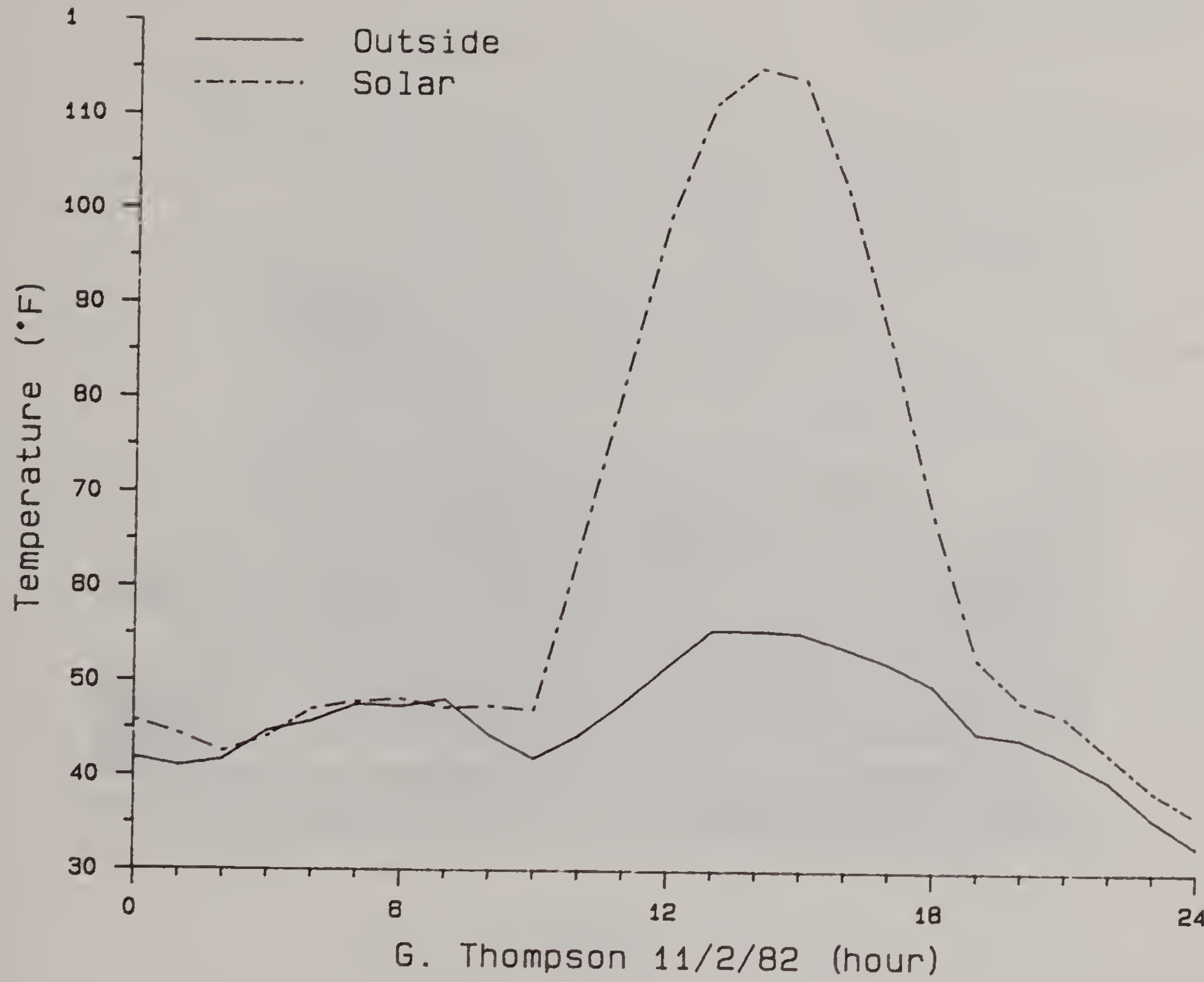


Figure GT7

Grain Drying Operation:

The 21.5 foot diameter grain bin was equipped with a 7 1/2 horsepower, 24 inch diameter axial flow fan with a LPG burner. The 3,400 bushels of corn were dried from 18.5% to 14.3% moisture content LPG was used some to assist in drying. About 9,300 pounds of moisture were removed which would require 14 million Btu of energy. The solar collector provided 8 million Btu or 14% of the total energy required.

Economic Feasability:

Twenty-five percent of the collector cost was used in the economic analysis for the grain drying portion. The collector will be used to heat the family home when it is not being used for grain drying. The economic analysis indicated a negative rate of return on the invested capital. In order to have a 10 year payback 0.86 gallons of LPG would have to be saved for grain drying.

Wahl Solar Demonstration

Larry Wahl
Rural Route 3
Wheaton, KS 66551

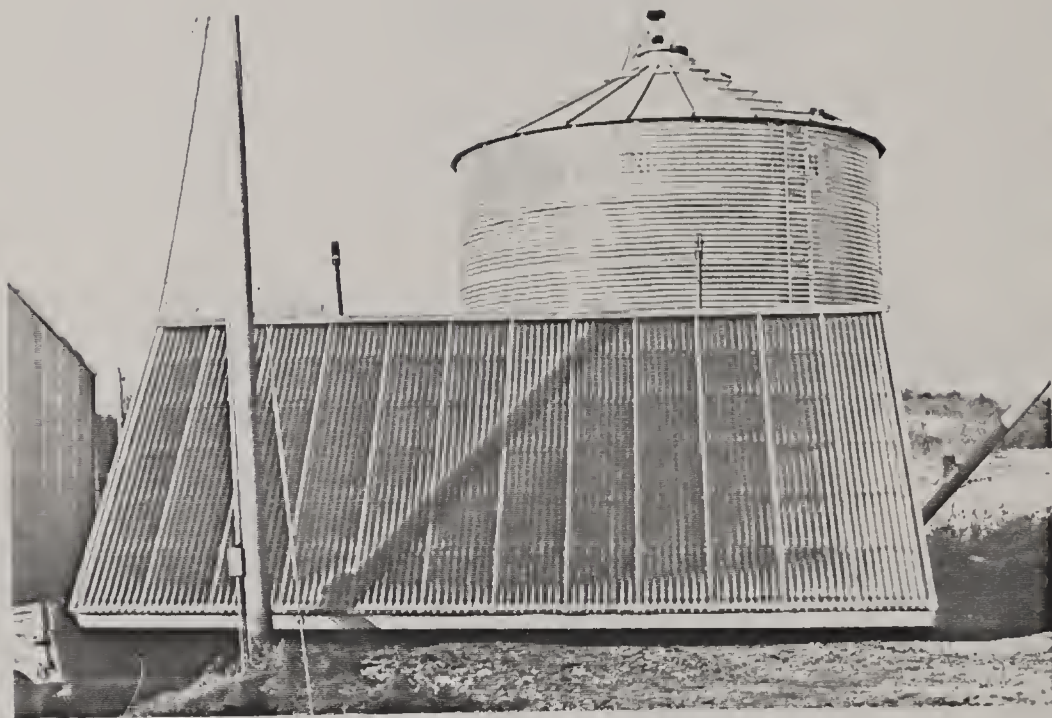


Photo W1

Solar Collector:

A 288 square foot collector was constructed using plans developed by a farmer in Nebraska. The young collector, named after its farmer-designer, is a single glazed suspended flat plate collector. When used for grain drying, airflow over and under the corrugated flat black painted absorber is in the same direction. When the unit is used to heat the home or shop, airflow is in opposite directions. The glazing consists of corrugated fiber glass. Figure W1 is an exploded view of the young collector.

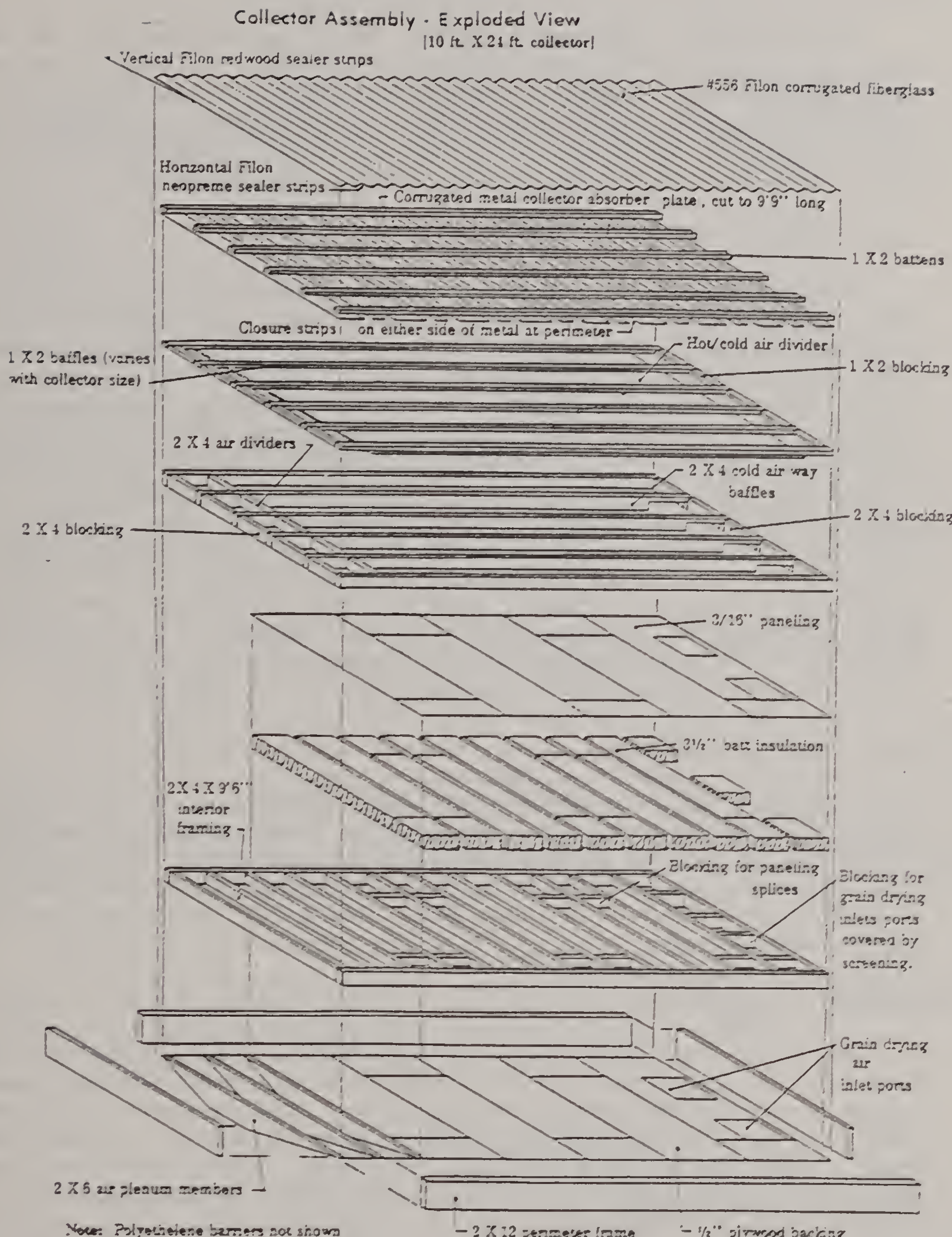

Collector Assembly - Exploded View
(10 ft. X 24 ft. collector)
Vertical Filon redwood sealer strips
#556 Filon corrugated fiberglass
Horizontal Filon neoprene sealer strips
Corrugated metal collector absorber plate, cut to 9'9" long
1 X 2 battens
Closure strips on either side of metal at perimeter
1 X 2 baffles (varies with collector size)
Hot/cold air divider
1 X 2 blocking
2 X 4 air dividers
2 X 4 cold air way baffles
2 X 4 blocking
2 X 4 blocking
3/16" paneling
3½" batt insulation
2X4X9'6" interior framing
Blocking for paneling splices
Blocking for grain drying inlets ports covered by screening.
Grain drying air inlet ports
2 X 6 air pleaum members
Note: Polyethelene barriers not shown
2 X 12 perimeter frame
½" plywood backing

Figure W1

For the Wahl demonstration, the collector was constructed 12 feet x 24 feet. This is 2 feet taller than the original design. It was mounted on a four wheeled trailer for portability. The collector angle tilt could also be adjusted for optimum exposure.

The collector cost was $2,800 or $9.72 per square foot of collector. In an earlier study of the young collector by Walter G. Heid, Jr., USDA, Agricultural Economic Report No. 466, the collector cost was reported to be $#5.46 per square foot. This figure excluded the running gear and labor. Photo W1 shows the collector connected to the grain bin. A utility pole caused slight shading during its use.

Measured Performance:

The collector was not ready for grain drying until November 30, 1982. It was used intermittently on seven days from November 30 through December 14, 1982. Air was ducted to the collector thourgh two uninsulated 18 inch diameter corrugated plastic ducts. The bin fan was used to pull air through the collector. One duct was for air traveling over the top of the absorber while the other duct was for air traveling under the absorber plate. Solar heated air temperatures were measured as well as airflow rates in each duct. Airflow over the absorber plate was 177 cfm while airflow under the absorber plate was 707 cfm. Average airflow rate was determined to be 3.1 cfm per square foot of collector. The collector provided an equivalent of 0.02 gallons of LPG per square foot of collector during its short time of use. We did not have sufficient data to determine collector efficiency, however, it was reported in Agricultural Economic Report No. 466 by Walter G. Heid, Jr. that collector efficiency averaged 65% on clear days of the drying season.

Grain Drying Operation:

The collector was used to dry 2,500 bushels of grain sorghum from 17% to 15% moisture content. The 18 foot diameter bin equipped with a 1 1/2 horsepower drying fan was partially filled before the collector was ready for use. Approximately 3,300 pounds of moisture were removed from the grain requiring 4.9 million Btu. The solar collector provided 11% of the total energy.

Economic Feasability:

Based on the 1982 fall drying period, our economic analysis resulted in a negative return to investment even when we considered only 25% of the collector cost in the analysis. The collector would need to save 0.19 gallons of LPG per square foot to have a 10 year payback. Under normal operating conditions this most likely could be achieved. The operator indicated that during the short period of use not many sunny days were available.

Summary

The following table gives the summarized results for the 1982 fall solar grain drying demonstration.

Name	Collector area ft²	Collector cost[a] apportioned to grain drying $/ft²	Energy saved for grain drying gal LPG/ft²	Economic[b] Rate of Return %
Davis	224	7.04	0.05	>0
Gigstead	1120	0.57	0.12	18
Henke	224	6.27	0.07	>0
Keesecker	840	1.39	0.47	30
Parmley	288	3.28	0.52	11
Runft	160	7.75	0.14	>0
Schroeder	198	5.05	0.64	>
A. Thompson	104	14.34	0.10	>0
G. Thompson	98	11.03	0.25	>0
Wahl	288	2.43	0.02	>0

a. These costs represent 25% of the actual collector cost for multiple use collectors. They were all multiple use collectors except Parmley's. One hundred percent of the collector cost was used in the economic analysis for the Parmley demonstration.

b. The rate of return is an inflation-adjusted after-tax annual rate based entirely upon the 1982 fall performance data.

The weighted average cost of all the collectors was $3.17. The six collectors with a negative rate of return averaged $6.82 per square foot and replaced an equivalent of 0.08 gallons of LPG. In order for them to have a 10 year payback, they would have to save 0.53 gallons of LPG. The four collectors with a positive rate of return had an average cost of $1.53 per square foot of collector and based on the 1982 fall demonstration had a 18% inflation-adjusted after-tax annual rate of return.

Approximately 175,000 thousand pounds of moisture were removed from 65,300 bushels of grain dried in this demonstration. We estimated that 260 million Btu of energy were required for its removal. Approximately 30% of this energy was obtained from the solar collector.

Educational Activities

Information on solar grain drying has been presented through meetings, radio, news, journals, energy fairs and individual contact with interested farmers. Two identical 4 foot x 8 foot solar collectors were displayed at the 1981 Kansas State Fair to demonstrate how different amounts of energy could be collected with different airflow rates through the collectors.

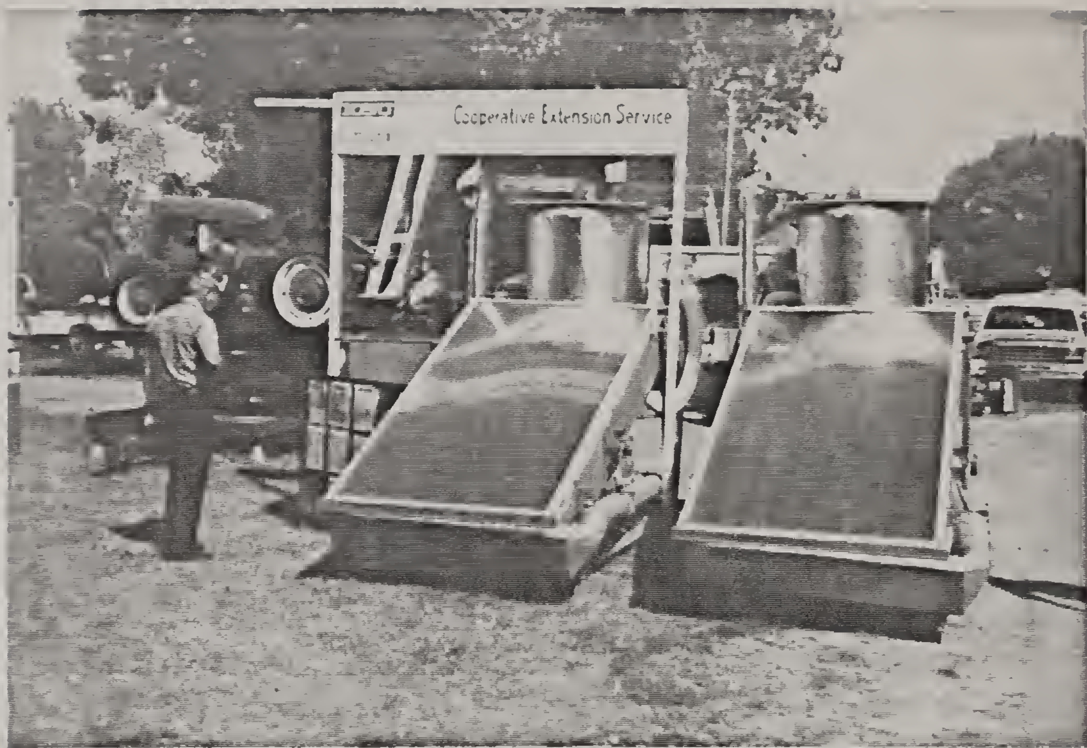


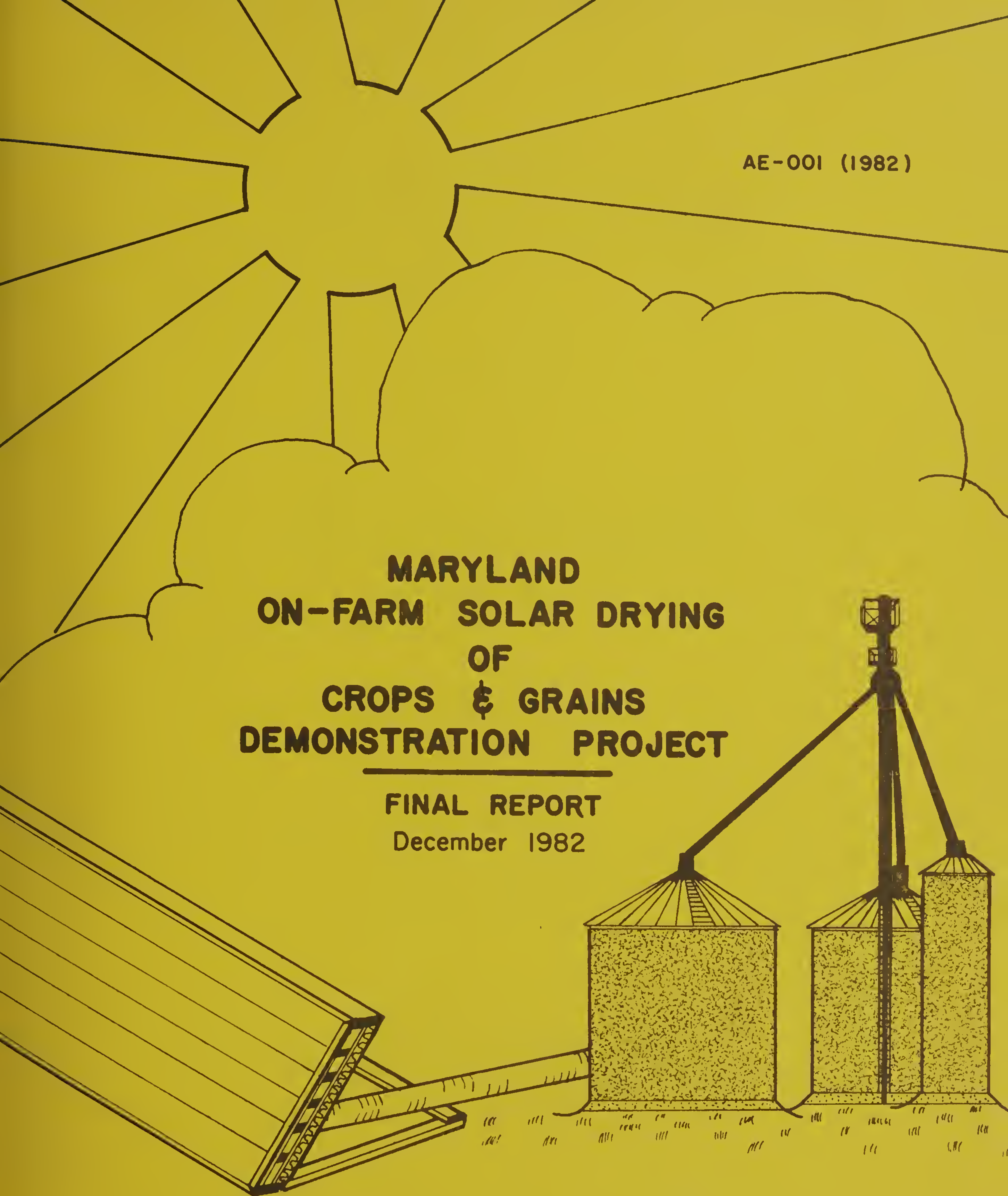
Photo E1

Over 250 handbooks on Low Temperature and Solar Grain Drying, MidWest Plan Service publication No. 22, have been distributed throughout Kansas during the past two years.

Appendix

Conversion table-English to metric units		
To convert from	To	Multiply by
$Foot^2$	$Meter^2$	.0929
$Mile^2$	$Kilometer^2$	2.590
Acre	Hectare	.4047
British thermal unit	Joule	1055
Foot	Meter	.3048
Horsepower	Watt	745.6
$Foot^3$	$Meter^3$	.0283
Gallon	Liter	3.785
Bushels	Tonne	.0263
Btu/ft^2-hr, day, etc.	$kWh/meter^2$-hr, etc.	.00315
Btu/ft^2-day	Langley/day	.2710
Cfm/bu	$Meter^3$/min-tonne	1.075

AE-001 (1982)



MARYLAND ON-FARM SOLAR DRYING OF CROPS & GRAINS DEMONSTRATION PROJECT

FINAL REPORT

December 1982

Larry E. Stewart & Gerald E. Berney
DEPARTMENT OF AGRICULTURAL ENGINEERING
Cooperative Extension Service
University of Maryland
College Park, Maryland 20742

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245 FINAL REPORT
for the
MARYLAND EXTENSION DEMONSTRATION
of
ON-FARM SOLAR DRYING OF CROPS AND GRAINS //

Submitted to

Office of the Administrator for Extension
Science and Education Administration
United States Department of Agriculture
Washington, D.C. 20250

by

The Department of Agricultural Engineering
Cooperative Extension Service
University of Maryland
College Park, Maryland 20742

In fulfillment of requirements of USDA
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December 1982

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for the
MARYLAND EXTENSION DEMONSTRATION
of
ON-FARM SOLAR DRYING OF CROPS AND GRAIN
by
Larry E. Stewart and Gerald E. Berney*

THE MARYLAND SOLAR DEMONSTRATION PROJECT

Introduction

Maryland farmers are extensive users of fossil fuels for drying grains. In 1979 over 80 million bushels of corn, wheat, barley and soybeans were produced on Maryland farms. Approximately 1.9 million gallons of LP gas were used for grain drying in Maryland with over 21 million bushels of grain being stored on farms. Rising costs and questionable availability of fuel for drying have increased interest of Maryland farmers in alternative energy technology and in various conservation practices applicable to grain harvesting, drying, storage and marketing.

Maryland is located in the mid-Atlantic Region where the fall harvest season is typically hot and humid. Also grain farms in the

*Dr. Stewart, Project Manager, is Chairman, Department of Agricultural Engineering, University of Maryland. Mr. Berney, Project Engineer, is Faculty Extension Assistant, Cooperative Extension Service, Department of Agricultural Engineering, University of Maryland. Acknowledgment is also given to numerous individuals who have contributed to this project: John Gird, Robert Muller, Robert Yeck and Ken Felton, Department of Agricultural Engineering, for technical advice and aid in farm selection and system design; Jarvis Cain, Department of Agricultural and Resource Economics, for aid in economic analysis of systems; numerous Extension Agents - Agricultural Science, Maryland Cooperative Extension Service, for aid in promoting the project and identifying prospective farmer-cooperators; and the Maryland farmers who have participated in the demonstration.

area tend to be large and have generally adopted rapid harvest and drying procedures. Thus, experience with low-temperature drying has been limited and, prior to this project, solar drying has not existed.

Research experience in Maryland on the use of solar energy for application to broiler brooding resulted in data that indicated that sufficient solar energy was available in Maryland to justify an evaluation of the applicability of solar energy to Maryland's grain drying industry. As a result, the Department of Agricultural Engineering, through the University of Maryland Cooperative Extension Service, proposed this project to demonstrate and evaluate the feasibility of solar grain drying in Maryland.

The Department of Agricultural Engineering was awarded funding by the U.S. Department of Agriculture for the project. The project was carried out under USDA Cooperative Agreement No. 12-05-300-509 with pass-through funds provided by the U.S. Department of Energy.

Under this project farmer-cooperators were to be reimbursed for one-half the cost of construction of a solar system designed, tested and monitored by the Department of Agricultural Engineering. This report describes the goals of the project and project management, farm selection procedures, systems monitoring, energy performance evaluations, economic evaluations and problems and solutions. In addition, detailed reports based on one season of operation for active farmer-cooperators are provided. Educational programs conducted and planned are also reported.

Project Goals

In general, the Maryland solar drying demonstration project was established to evaluate whether low-temperature solar drying systems were viable alternatives for application in the humid mid-Atlantic Region.

The specific objectives of the Maryland solar drying project included the following:

1. To evaluate various alternative designs of solar crop drying equipment for applicability to Maryland's climate.
2. To demonstrate the technical and economic feasibility of using solar energy technology for on-farm grain drying in Maryland.
3. To identify multiple-use solar applications and thus increase farmer acceptance of systems that prove to be the most practical.
4. To increase the knowledge of Maryland Extension agents about the potential for solar energy applications.
5. To provide Maryland farmers with information that can be used to: (1) evaluate solar grain drying potential, (2) make wise choices in equipment selection, (3) develop multiple uses of solar collectors, and (4) provide operational instructions to optimize performance.

Project Management

A team of individuals was responsible for the Maryland demonstration project. The only member of the team employed on project funds was the Faculty Extension Assistant who assumed major responsibility for implementing the details of the project. All other personnel were University of Maryland faculty who contributed their time and talent to the demonstration effort. Names of participants are listed on page 1 of this report. Duties of the project team were as follows:

Project Manager - Prepared the pre-proposal and final proposal for submission to USDA. Upon award of the contract, he was responsible for

the overall management of the project, including participation in final selection of cooperators, participation in the design phase of the project, completion of agreements with cooperators and other details of the project. He was responsible for coordinating the activities of the project team, for approving all purchases under the contract, for employing a faculty extension assistant, technical reports for the project and for coordinating the educational activities.

Faculty Extension Assistant - In cooperation with the Project Manager and the Engineering and Technical Advisors, the FEA participated in the selection of farmer-cooperators, in the development of systems designs, in supervising system construction and installation, in acquisition of instrumentation and supplies, in system monitoring and in the evaluation of individual systems.

Engineering and Technical Advisors (four) - They had an active role in final farmer-cooperator selection, systems design and advised on system construction, instrumentation, data collection and analysis and in system evaluation. They will also have an active role in preparation of educational materials and programs in the future.

Project Economist - Developed a format for the collection of all data needed to evaluate the economics of existing farm systems and the solar systems added to these farms. Details of the economic analysis are discussed later in the report.

Extension Agents - Agricultural Science - Helped locate prospective cooperators and served as liason between the project team and the farmer-cooperators. They will also be key individuals in the planned outreach aspects of the project.

Farmer-Cooperators - Were responsible for the construction and installation of their solar system according to specifications provided

by the Department of Agricultural Engineering. They were to provide detailed and accurate records of the materials and labor required for the installation of the solar system and were reimbursed for one-half the system cost. Farmers aided in the collection of pertinent data relative to the operation of the system and provided suggestions on the solution to problems encountered in construction and operation. At the end of the project, the system fully becomes the property of the farmer, except for some instrumentation which reverts to the Department of Agricultural Engineering. All farmers were also willing to participate in educational aspects of the project.

Procedures for Selecting Participating Farms

During 1981 over 35 potential farm cooperators were visited by members of the project team. During each visit an evaluation of the energy and economic potential of a solar system was completed. Factors considered in the evaluation included:

1. Physical arrangement of the grain drying system
2. Farmer experience in grain drying
3. Potential for multi-use of solar energy on the farm
4. Potential energy savings to be accrued
5. Potential for economic pay-back of the system
6. Location of the farm relative to the demonstration aspects of the project; i.e., ease of access for tours, individual farm visits by farmers and news personnel
7. Willingness of farmers to receive visitors
8. Ability of farmers to provide up-front funds for the construction of the system

9. An assessment of the farmer's overall management ability
10. An assessment of the farmer's ability to adapt to the required management for low-temperature solar drying

The selection process was time consuming and difficult because of the general lack of experience in solar grain drying in Maryland. Many interested potential cooperators were rejected if it did not appear that the system could be justified on a reasonable economic base. In retrospect, the intitial screening removed some potential cooperators who would have completed their systems even though the project team did not feel the economics of the system justified the demonstration. Perhaps a more lenient approach would have produced ten active participants, which was the original intent of the project.

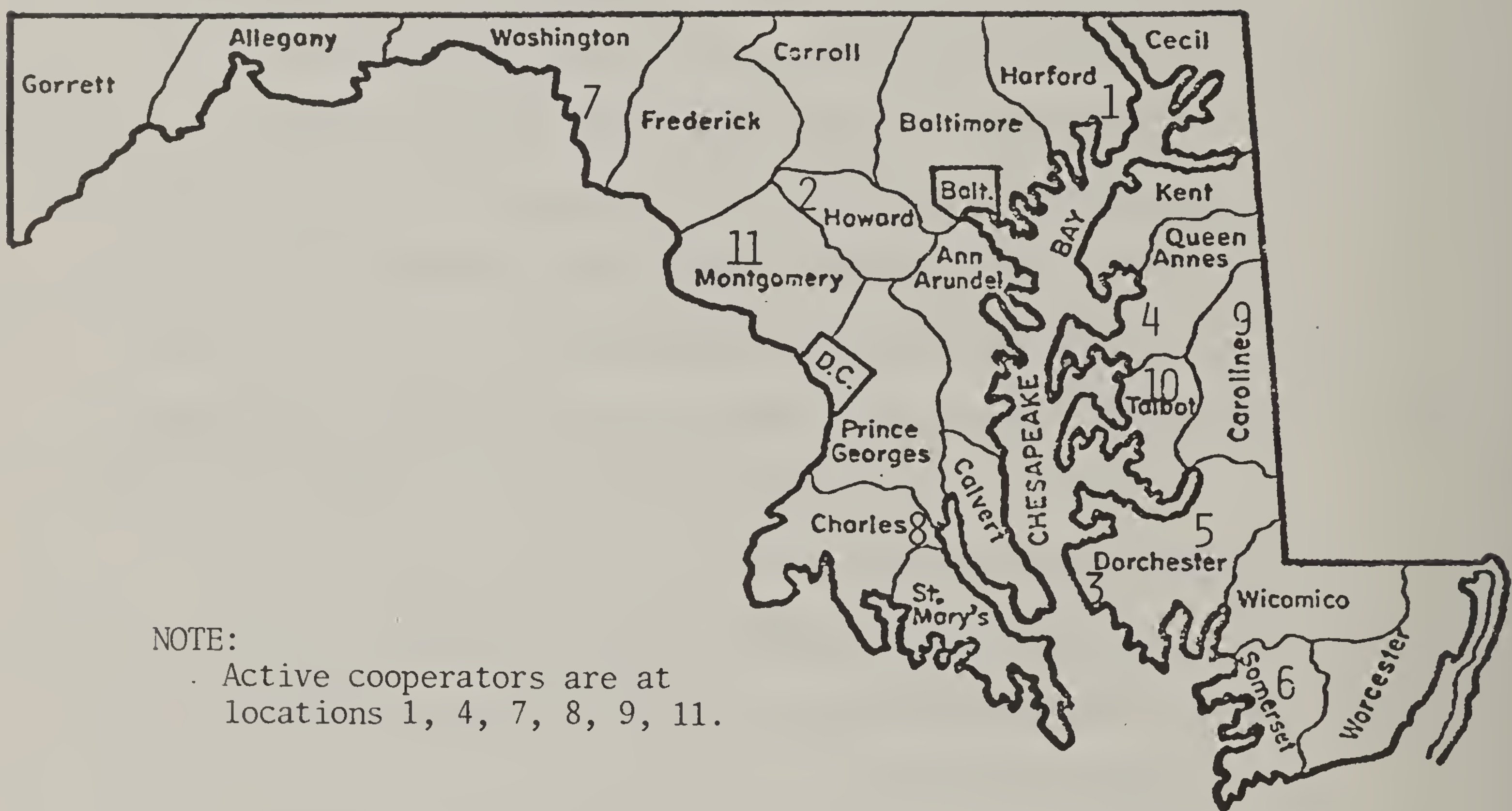
Subsequently, eleven (11) farm solar systems were designed and prepared for submission to Peer Review by USDA. The submissions to USDA included information on the location of the farm, a description of the total farm operation including a past history of energy use and grain drying experience, goals and objectives of the demonstration on that specific farm, a completed solar system design, an estimate of construction costs, an evaluation of the economic potential for the system and a description of the instrumentation, monitoring and system evaluation to be used. Appropriate drawings of the physical facilities and the solar system were included.

As a result of these submissions to the USDA Peer Review Panel, 11 systems were approved for construction in Maryland as follows:

1. Thomas L. Adams, Churchville, portable Purdue free-standing collector for drying of corn and small grains.

2. Roy Crum, Jr., Woodbine, new shop building with attic collector, grain drying plus shop heating.
3. Michael Jones, Taylors Island, Purdue portable free-standing collector for grain drying and swine farrowing.
4. Reed Leaverton, Centreville, Portable Purdue free-standing collector for grain drying and dairy applications.
5. David Meyer, Cambridge, Portable Purdue free-standing collector, grain drying and broiler brooding.
6. Thomas Pinto, Princess Anne, roof-retrofit collector, grain drying, broiler house heating and farm shop heating.
7. Leon Price, Sharpsburg, wrap around collector, single purpose corn and small grain drying.
8. Franklin Robinson, Benedict, portable Purdue free-standing collector for grain drying, shop heating, lambing and tobacco stripping room heating.
9. James and Gary Schoonover, Greensboro, Portable Purdue free-standing collector for grain drying and possible broiler brooding.
10. William Willis, Longwood, retrofit roof collector for shop heating and grain drying.
11. Frank Wilmot, Gaithersburg, roof, south wall and horizontal collector, single purpose batch hay drying operation with some preliminary grain drying trials.

Figure 1 indicates the geographic distribution in Maryland of the farms approved for involvement in the demonstration project.



NOTE:
- Active cooperators are at locations 1, 4, 7, 8, 9, 11.

Figure 1. Location of farm cooperators approved by USDA for participation in the Maryland solar grain drying demonstration project.

Farmers Who Withdrew from the Project

As previously reported in Quarterly Progress Summaries, five of the cooperators withdrew from the project. Those withdrawing included the Crum, Jones, Meyer, Pinto and Willis farms. Many different reasons were cited for their decisions and these reasons are presented here for consideration by national project management when establishing future demonstration projects.

1. There was too much time between submission of proposed projects and receiving approval for beginning of construction.
2. Excessively high interest rates caused farmers to avoid borrowing capital.
3. The fact that farmers had to pay for the entire system "up-front" before reimbursement.
4. General state of economy and its affect on farm grain prices.
5. Stabilization of costs and availability of energy.
6. Second thoughts due to lack of confidence in low-temperature drying.
7. Concerns that the expected economic pay-back period was too long.
8. Decisions to delay construction of new buildings until the economy improved.
9. Decisions to spend funds on additional grain drying and storage equipment rather than build a collector.

These farmers declined to participate after expressing their intent to cooperate. However, individual circumstances prevented their continuation even though the project team had invested a significant amount of effort in system design and planning.

Unfortunately most of the withdrawal decisions were made after the final date for Peer Review Panel meetings and thus substitute cooperators could not be added. This fact, coupled with the one year reduction in DOE project support reduced the number of active participants to six.

Active Project Participants

Of the six active project participants, four completed construction in time for collection of data to evaluate performance of the solar system. These four included the following:

1. Leon Price, Sharpsburg, Md., constructed a 1200 sq. ft. wrap around collector at a total cost of $3428.89 or $2.85 per square foot.

2. Franklin Robinson, Benedict, Md., constructed 1152 sq. ft. of the modified Purdue type portable collector at a total cost of $6252.60 or $5.42 per square foot.

3. James and Gary Schoonover, Greensboro, Md., constructed 576 sq. ft. of the modified Purdue type portable collector at a total cost of $3505.10 or $6.08 per square foot.

4. Frank Wilmot, Gaithersburg, Md., constructed 1400 sq. ft. of collector as an integral part of a batch hay drying operation at a total cost of $3900. The average cost per square foot of collector was $2.78.

Details of each of the above designs are presented in individual publication in the Appendix of this report. A fifth publication on how to build the modified Purdue collector is also presented in the Appendix.

The other two cooperators, Thomas Adams of Churchville, Md., and Reed Leaverton of Centreville, Md., were not able to complete construction prior to the 1982 drying season. Construction was begun and hopefully will be completed in time for small grain drying during the spring of 1983.

Systems Monitoring and Energy Evaluation Procedures

A number of important parameters were monitored at each operating solar system. These parameters included key system temperatures, grain moisture, electrical and LP gas useage, air flow and incident solar radiation. A brief description of each follows.

Temperatures. Temperatures were measured at key points in each system using ANSI type T thermocouples and an Omega multi-point thermocouple indicator. Key points in all systems included the following temperatures: air entering the collector, air exiting the collector and air entering the bin. In those systems which did not have stirring augers, a cable was placed in the bin in order to measure temperatures within the grain mass. Measurements for a typical day were taken hourly.

Grain Moisture Content. Moisture content measurements were taken by the farmers for each load of grain placed in or removed from the dryer.

Electricity and LP Gas Useage. Electrical useage was monitored in two ways. On farms with separately metered drying installations, data was taken from power supplier bills. For farms without separate electrical meters, a record of hours of fan operation was maintained. The electrical power useage was then calculated using the power ratings of the fans. LP gas useage was taken from billings provided by the farmers.

Air Flow. Air flow on each farm was measured with an Alnor hot-wire anemometer. The duct from the collector to the fan was probed, air velocities measured and then air flow was calculated from these data and duct dimensions.

Incident Solar Radiation. Solar radiation was measured with an Epply B&W pyranometer and a Licor millivolt integrator. In the case of the portable collectors, the pyranometer was mounted at the same slope as

the collector. For installations with more unusual geometry, measurements were made with the pyranometer mounted on a horizontal surface. Measurements for a typical day were hourly integrated values.

Energy Evaluations. The thermal performance of the solar collector was evaluated for a typical day during the drying season. The energy output of the system was calcualted using the monitored values of air flow and temperatures. Because relative humidity and barometric pressure were not recorded on site, a constant specific heat (.24 Btu/lb) and a constant volume/mass ratio (14 ft^3/lb) were assumed. Hourly and full day efficiencies were calculated by dividing the energy output by the solar energy incident on the collector surface.

Energy Savings. Energy savings were computed and are reported as follows:

1. Fossil fuel replaced - was the equivalent amount of LP gas equal to the total heat output of the solar collector over the drying season.

2. Energy saved - was the equivalent amount of LP gas equal to the heat output of the collector minus the sum of the LP gas used (if any) and the increased electrical useage.

3. Energy per pound of water removed - was the total amount of energy (solar + electrical + fossil) used to dry the grain or hay divided by the weight of moisture removed in the drying process.

4. Purchased energy per pound of water removed - was the amount of electrical and fossil energy used divided by the amount of water removed in drying. This value was calculated to provide a more valid comparison between the solar systems and any conventional systems where all energy inputs must be purchased.

In summary, the results for the four farms that operated during the fall of 1982 are as follows:

1. Leon Price Farm

   Units Dried - 8300 bushels of corn from 24-15.1% moisture

   Average Daily Collector Efficiency - 48%

   Solar Energy Collected - 15.4 million Btus

   Drying Time - 21 days

   LP Gas Replaced - 178.1 gallons

   Purchased Energy Per Pound of Moisture - 1075 Btus/lb

2. Franklin Robinson Farm

   Units Dried - 4800 bushels of corn from 26.75-15% moisture

   Average Daily Collector Efficiency - 57%

   Solar Energy Collected - 29.8 million Btus

   Drying Time - 16 days

   LP Gas Replaced - 342.6 gallons

   Purchased Energy Per Pound of Moisture - 291 Btus/lb

3. Schoonover Farm

   Units Dried - 32,400 bushels corn from 20-14% moisture

   Average Daily Collector Efficiency - 89%

   Solar Energy Collected - 46.9 million Btus

   Drying Time - 40 days

   LP Gas Replaced - 539 gallons

   Purchased Energy Per Pound of Moisture - 848 Btus/lb

4. Wilmot Farm

   Units Dried - 150 tons of alfalfa from 30-10% moisture

   Average Daily Collector Efficiency - 36.4%

   Solar Energy Collected - 60 million Btus

Drying Time - 40 days

LP Gas Replaced - 723 gallons

Purchased Energy Per Pound of Moisture - 1330 Btus/lb

Economic Evaluations

Because the systems were not all operated for a full drying season and because there were problems in learning new management procedures and because of mechanical problems that occurred, it is not possible or practical to completely evaluate the economics of the individual systems. However, each of the installed systems seems to have the potential for reasonable economic returns to the farmer. Simple pay back periods were computed for the systems:

1. Price - 6.3 years
2. Robinson - 7.2 years
3. Schoonover - 8.1 years
4. Wilmot - 5.6 years

Obviously these pay back estimates are conservative. They do not take into account any benefits of alternate uses of the collectors, energy tax credits available from federal or state sources, increased costs of LP gas that may occur in the future or improved system operating efficiency as the operators gain management experience. In addition, most farmers will use the system for small grain drying in the spring to allow earlier harvest and earlier planting of double crops. The potential economic returns of the latter may be greater than the value of saved energy.

Realistically, in Maryland the units should pay for themselves in no more than five years.

Educational Activities

Because Maryland has had no previous experience with low temperature solar crop drying, educational activities to date have been limited. It was felt that experience and data were needed before an effort was made to generate broad farmer interest and enthusiasm.

To date the following educational activities have been conducted:

1. Extension agents were provided information about the demonstration project and the potential farmer benefits from solar applications. This resulted in radio, newspaper and newsletter publicity throughout the state.

2. Thirty-five farms were visited and an evaluation of solar potential was made. Detailed system designs were developed for 11 farms.

3. News articles were included in the monthly Agricultural Engineering Newsletter that is distributed to 1500 key agricultural leaders of the state.

4. Numerous talks were presented to farmer groups at county and statewide meetings. The most effective presentations were made to 200 farmers at the annual meeting of the Maryland Grain Producers Association.

5. The Delmarva Farmer, a newspaper that reaches nearly all farm homes in Maryland, has had a feature article about the cooperating farms and plans a follow-up series during late winter now that evaluation data are available.

Many educational activities are planned for the future:

1. Tours of farmers will be organized regionally to show others what has been accomplished on the demonstration farms.

2. A series of publications is planned to aid farmers in planning, constructing operating and managing low temperature solar systems.

3. A graduate student research project is underway which will produce a computer model that will define key management parameters for low temperature drying in Maryland.

4. A slide-tape presentation on low temperature solar drying in Maryland will be developed and presented throughout the state.

5. A panel on solar grain drying will be included in a new farm energy exhibit.

Summary

This demonstration project has been both frustrating and rewarding to the participants. The project management team was disappointed that only six farmers actively participated in the program. However each of these farms is a very practical demonstration with reasonable economic returns to the farm.

Mechanical problems and the need to learn new management skills caused difficulties during the first drying season. These items are discussed in detail in the appended individual farm reports. However the farmer-cooperators generally have been extremely positive in their reactions to the systems. As additional management skills and experience are gained, the results should be even more favorable.

Based on experience gained, it appears that solar crop drying is a viable alternative for Maryland.

Cooperative Extension Service

AGRICULTURAL ENGINEERING FACTS

UNIVERSITY OF MARYLAND-COLLEGE PARK — UNIVERSITY OF MARYLAND-EASTERN SHORE

PREPARED BY SPECIALISTS — AGRICULTURAL ENGINEERING DEPARTMENT — UNIVERSITY OF MARYLAND
COLLEGE PARK, MD 20742

FACTS 139
January, 1983

THE SERENITY FARM SOLAR GRAIN DRYING DEMONSTRATION

by
Larry E. Stewart, Chairman and Gerald E. Berney,
Faculty Extension Assistant,
Department of Agricultural Engineering

Description of the Farm

Serenity Farm, owned by Franklin Robinson, is located about three miles northwest of Benedict, Maryland, on the north side of State Route 231, which is about 40 miles southwest of Washington, D.C.

Serenity Farm produces crops on 300 owned acres plus another 100 leased acres. Crops include corn, tobacco, potatoes, soybeans and seed rye. The farm also has a large flock of sheep and a swine herd. About

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914 in cooperation with the U.S. Department of Agriculture, University of Maryland and local governments. Craig S. Oliver, Director of Cooperative Extension Service, University of Maryland.

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15,000 bushels of corn and about 3000 bushels of rye for seed are harvested and dried annually. LP gas is used for fuel. The annual fuel usage varies considerably with weather conditions and the number of acres that are leased. Maximum LP gas usage has been approximately 2250 gallons annually.

The grain handling facilities were developed for acreages in excess of those that are now leased and, therefore, provide considerable flexibility in managing the drying operations. There are 4 circular steel bins. Three are equipped for drying; 1 - 36 ft. diameter and 2 - 18 ft. diameter. The 36 ft. bin is equipped with an auger type stirrer. The fourth bin is 27 ft. in diameter. Grain can be readily conveyed between bins. The 36 ft. bin (11,400 bu) was used with the solar system.

Goals and Objectives

1. The objective is to demonstrate the practicality of a solar grain drying system to farmers in the Mid-Atlantic region.

2. Specific goals are to:
   a. Design the most cost-effective solar facility and drying management system that fits the needs of Serenity Farm.
   b. Have the farmer construct the system.
   c. Monitor costs - construction and operating.
   d. Monitor drying effectiveness.
   e. Evaluate the cost-effectiveness.
   f. Conduct field days to demonstrate the system for interested farmers.

Solar System Design

A skid-mounted solar collector, closely patterned after the Purdue design (Figure 1) was the basic element of the solar system. Each collector has face dimensions of 12 ft. high by 16 ft. wide. The cover material was a single thickness of .04"FRP. The receiver was black-painted corrugated sheet metal and located 1.5 inches behind the cover with the corrugations in a vertical configuration. Another 3.5 inches air passageway was provided behind the receiver and the back was constructed of 1/2 inch plywood reinforced with 2 x 4 wood ribs. No insulation was added to the backing for grain drying but will be added to panels as needed when the panels are diverted to alternate uses. The tilt of the panels can be manually adjustable by moving pins in a sliding pipe brace. Only one position was used for the entire drying season.

Three panels were serially joined together by a wooden clamping system that could be vented if necessary. Air was drawn horizontally across both faces of the receiver. Thus, the total length of the air flow path across the 3 collectors was 48 feet. A second set of 3 panels was connected in parallel to the first set. The air movement is provided by two 7.5 HP Aerovent fans.

A mixing box for each set of collectors was used to provide the fan air demands beyond the 5 cfm/ft^2 of receiver (500 fpm face velocity) recommended for the Purdue Collector. The total collector area was 1152 sq. ft.

The 36 ft. diameter bin was used and a layer mode of drying recommended to the farmer. The layer depths depend on initial moisture contents and prevailing weather conditions. The initial layer is normally 4 ft. with subsequent layers at 3 to 4 ft. Grain moisture measurements were made to determine how frequently additional layers could be added, which is normally a layer every 5 - 7 days.

Alternate uses for the collectors during the winter season are: (1) an adjacent machinery repair shop - only a small blower and short additonal section of ducting will be required; (2) heating the tobacco stripping room for worker comfort (one or more of the collectors will need to be towed about 500 ft. for this use); (3) heat for the lambing shed (about a 500 ft. tow will be required for the collectors); and (4) possibly the home and farrowing house. The home and farrowing house will not as easily fit the solar application but is possible.
Note: Insulation (probably polystyrene boards) will need to be added to the backing for winter time use.

System Construction Costs

The 1152 sq. ft. of solar collector and ducting were constructed on the farm with farm labor. Costs of construction were as follows:

Materials Costs	\$4112.60
Labor (428 man hours @ \$5.00/hr)	2140.00
	\$6252.60

Thus the average cost per square foot of collector was \$5.42.

System Performance

Solar radiation was measured with an Eppley B&W pyranometer and a Licor millivolt integrator. The pyranometer was mounted at the same slope as the collector face. Measurements for a "typical day" were based on hourly integrated values.

The thermal performance of the solar collector was evaluated for a typical day during the drying season. The energy output of the system was calculated using measured values of air flow and critical temperatures. Because relative humidity and barometric pressures were not recorded on site, a constant specific heat (.24 Btu/lb.) and a constant volume/mass ratio (14 ft.^{3}/lb) were assumed. Hourly and full day efficiencies were calculated by dividing the energy output by the solar energy incident on the collector surface.

Typical day collector performance for the Serenity Farm collector is shown in Figure 2. Solar insolation received and collector efficiency are indicated. The daily average efficiency for this unit was 57 per cent.

In this first drying season, 4800 bushels of grain were dried from 26.75 to 15 per cent moisture. Sixteen days were required for drying the grain at an average cost of 3.86 cents per bushel. Electrical energy cost was $185.20 for 3660 kwh. The solar system provided 29.8 million Btu gallons of LP gas. Purchased energy per pound of moisture removed was 291 Btus per pound, indicating good system efficiency.

System Payback

Because the collector was available for only a portion of the drying season, it is necessary to extrapolate expected economic returns to the farm. Assuming the system will be fully utilized in subsequent years, it is believed that annual LP gas savings will reach 1150 gallons or 1 gallon per square ft. of collector per year. Assuming the cost of LP gas to be $.75 per gallon, the simple pay back period will be:

$$\$5.42/.75 = 7.2 \text{ years}$$

This estimate does not take into account expected increases in costs of LP gas or the energy savings that will accrue through other uses of the system. Also energy tax credits are not considered in this computation.

Operational Problems, Corrections and Other Management Factors

1. Some grain next to the bin wall did not dry well, even though stirring augers were operating. Some manual grain movement was nessary.

2. Stirring augers were operated continuously. If the augers had been operated only every 3 - 4 days, electrical energy use could have been reduced by 10 percent.

3. Some air leaks occurred in joints between collector units. These can be corrected by careful observation and use of caulking or tape.

4. Some paint is peeling from the absorber plates. Care in cleaning oil from new roofing material prior to paint application is essentia

5. Initially anchorage of the collector against wind loads was insufficient. This deficiency has been corrected by use of cables and ground anchors.

6. Airflow rates through the collector were excessive during the early

part of the drying season, causing large friction losses. Airflow rate has now been adjusted to a uniform 5 cfm ft.^{2} of collector area.

7. Collectors are less portable than originally expected. The joining of the collectors into groups of three causes inconveniences in moving them.

8. Management practices followed were excellent and should be continued:
   a. All grain was cleaned before it was placed in the bin.
   b. The grain surface in the bin was leveled after each loading so that airflow was as uniform as possible.
   c. Grain was placed in the bin as soon after harvest as possible.
   d. Drying fans were operated continuously during the drying period.

9. Stagnant air temperatures in the collectors have not been a problem with this system. The highest recorded temperature was less than 150°F.

Summary

The operator of this system, already convinced of the benefits of natural air drying, feels that the solar collectors add enough reliability to his system that he will not have to resort to the use of his LP gas heater again. He also states that the solar-supplied heat dried grain much faster than would have the natural air only method.

To simplify descriptions, trade names of equipment and materials have been used. No endorsement is implied, nor is discrimination against similar products intended.

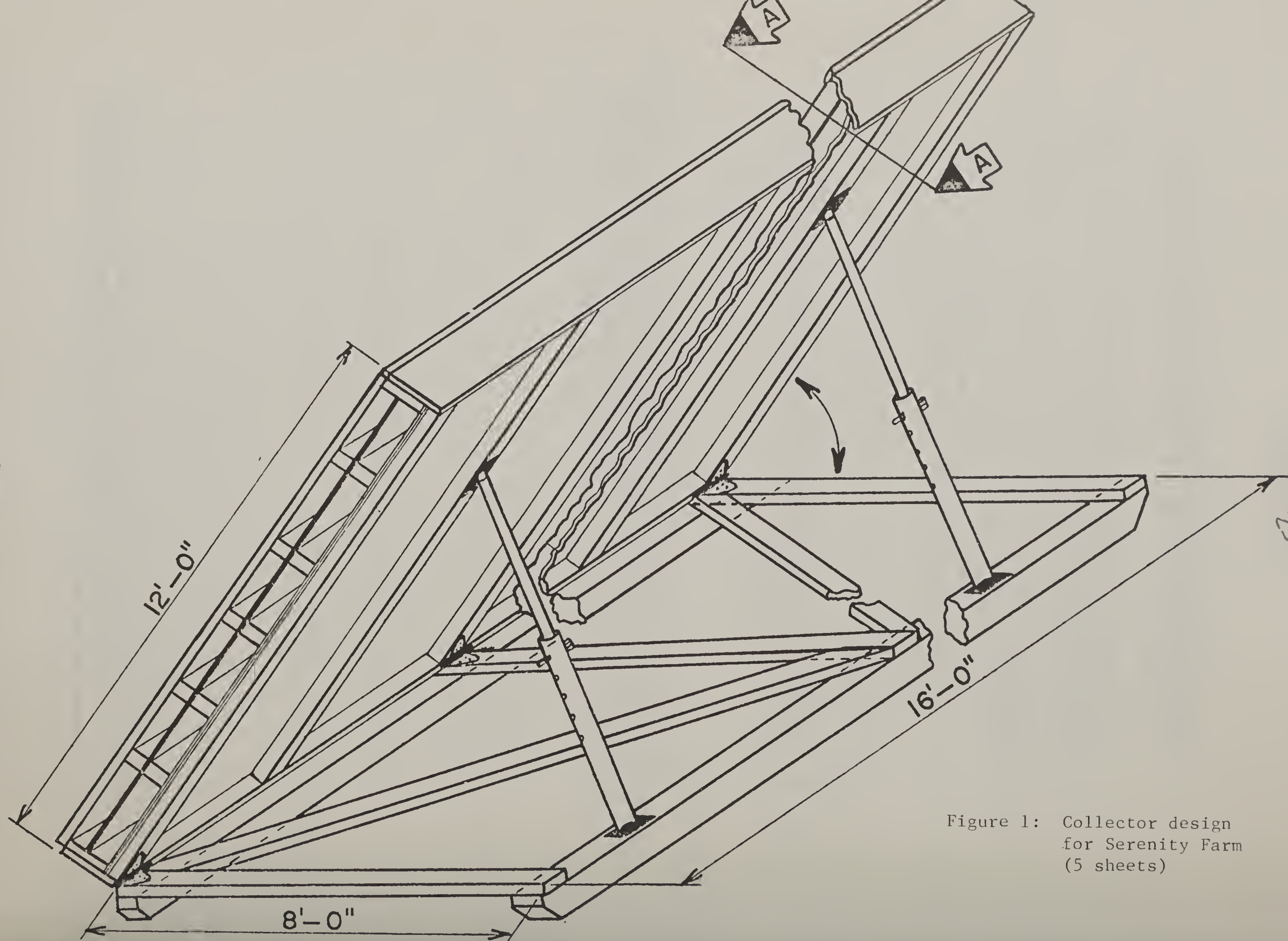

Figure 1: Collector design for Serenity Farm (5 sheets)

PORTABLE SOLAR COLLECTOR

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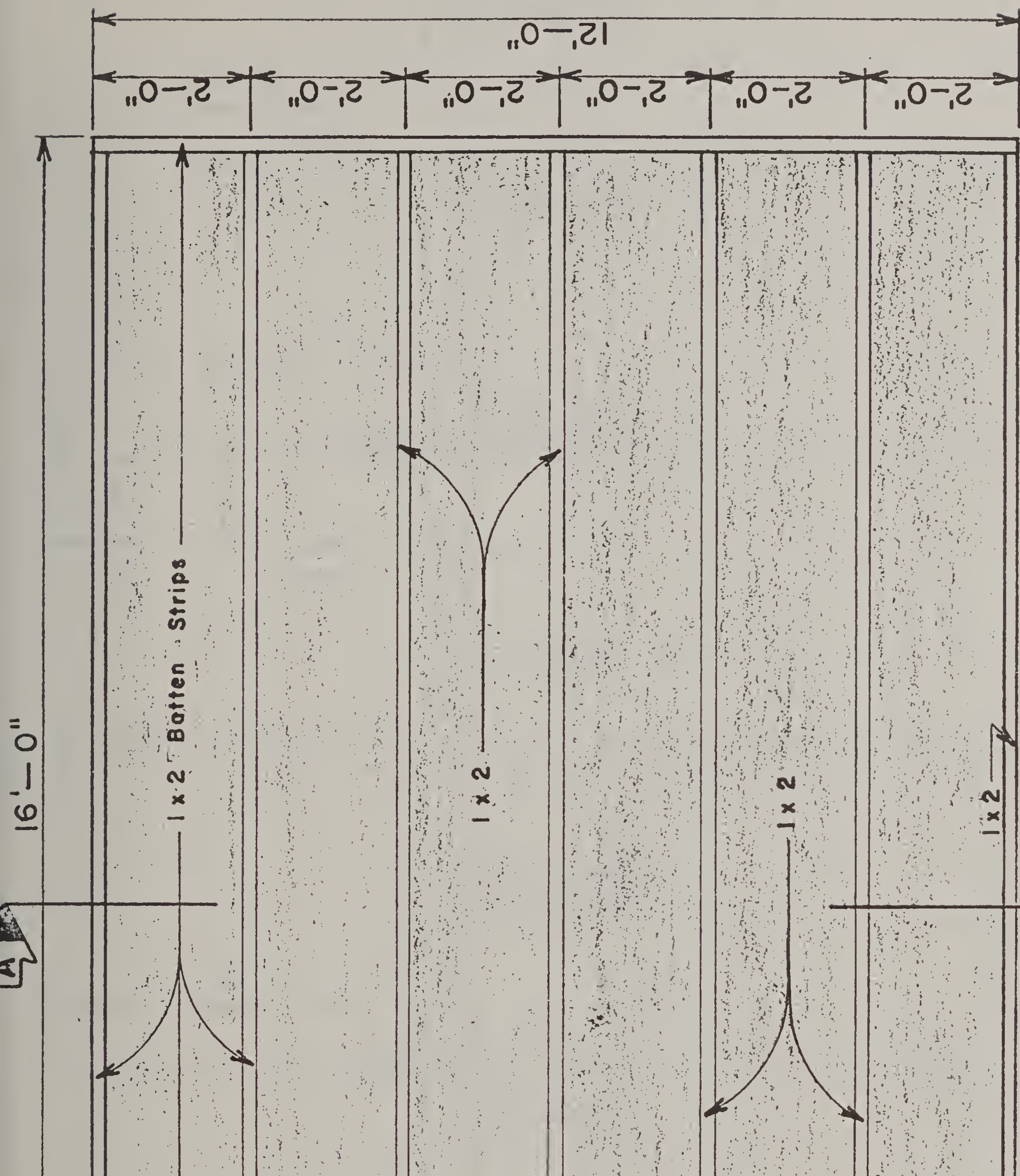
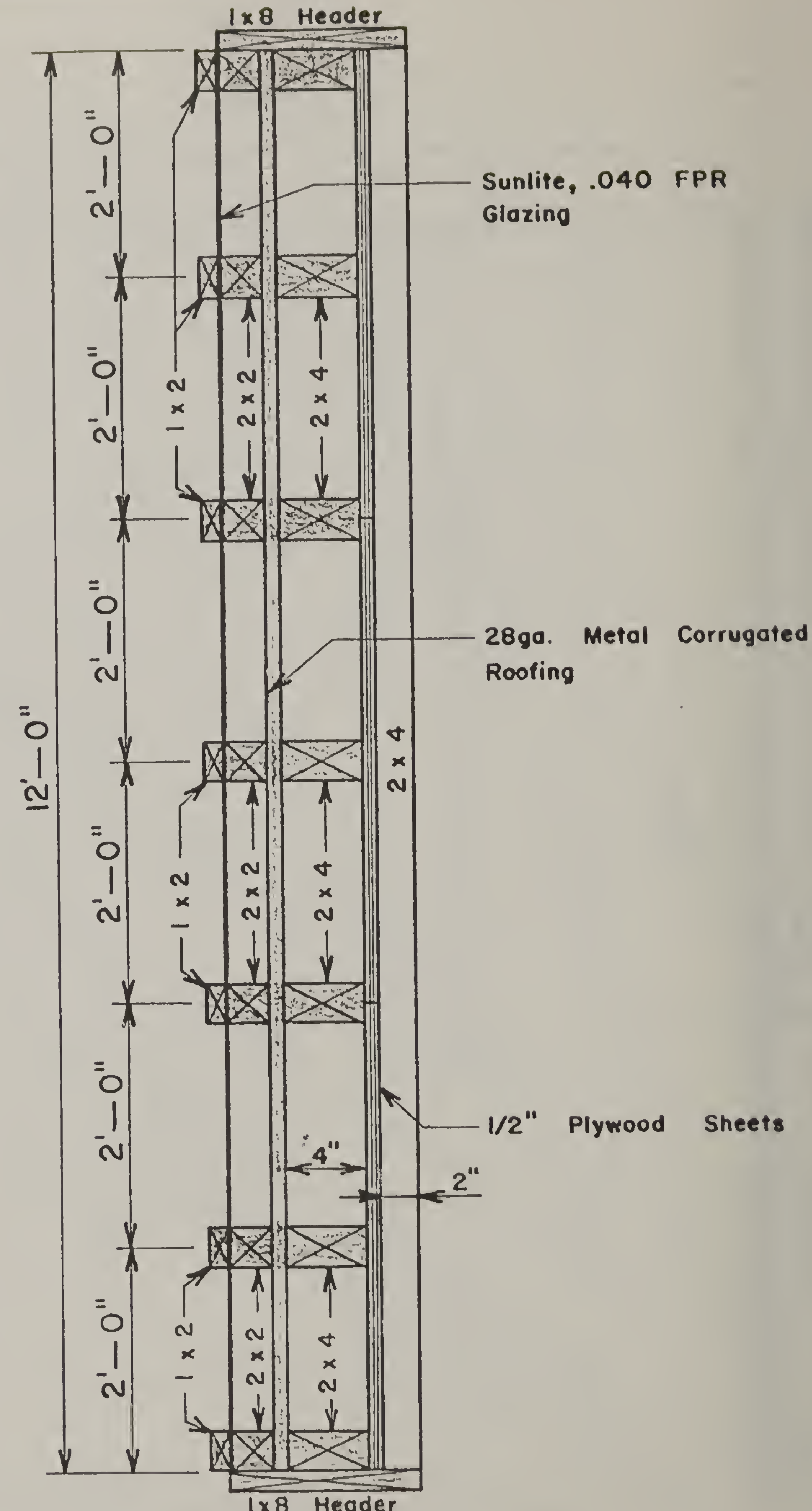
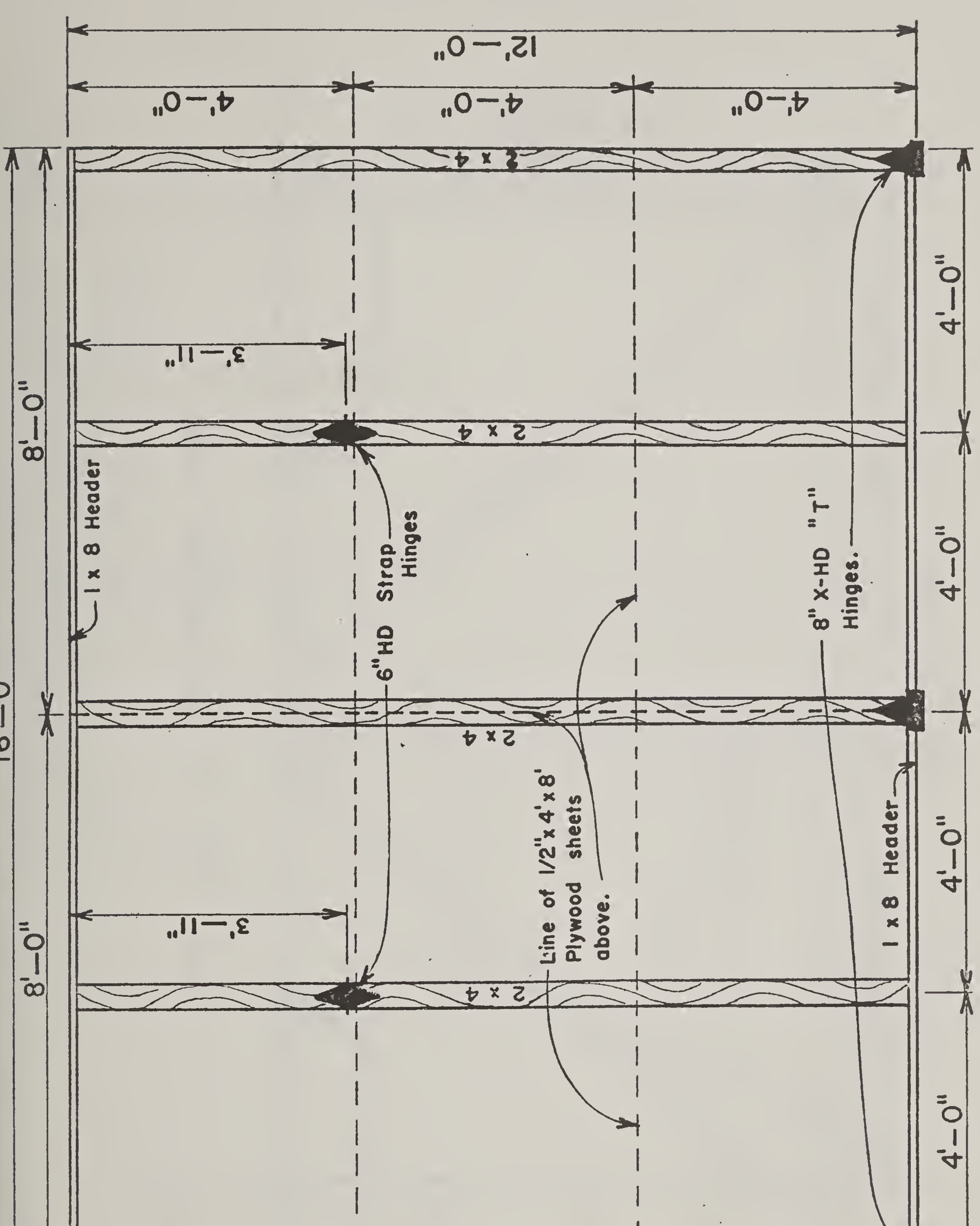


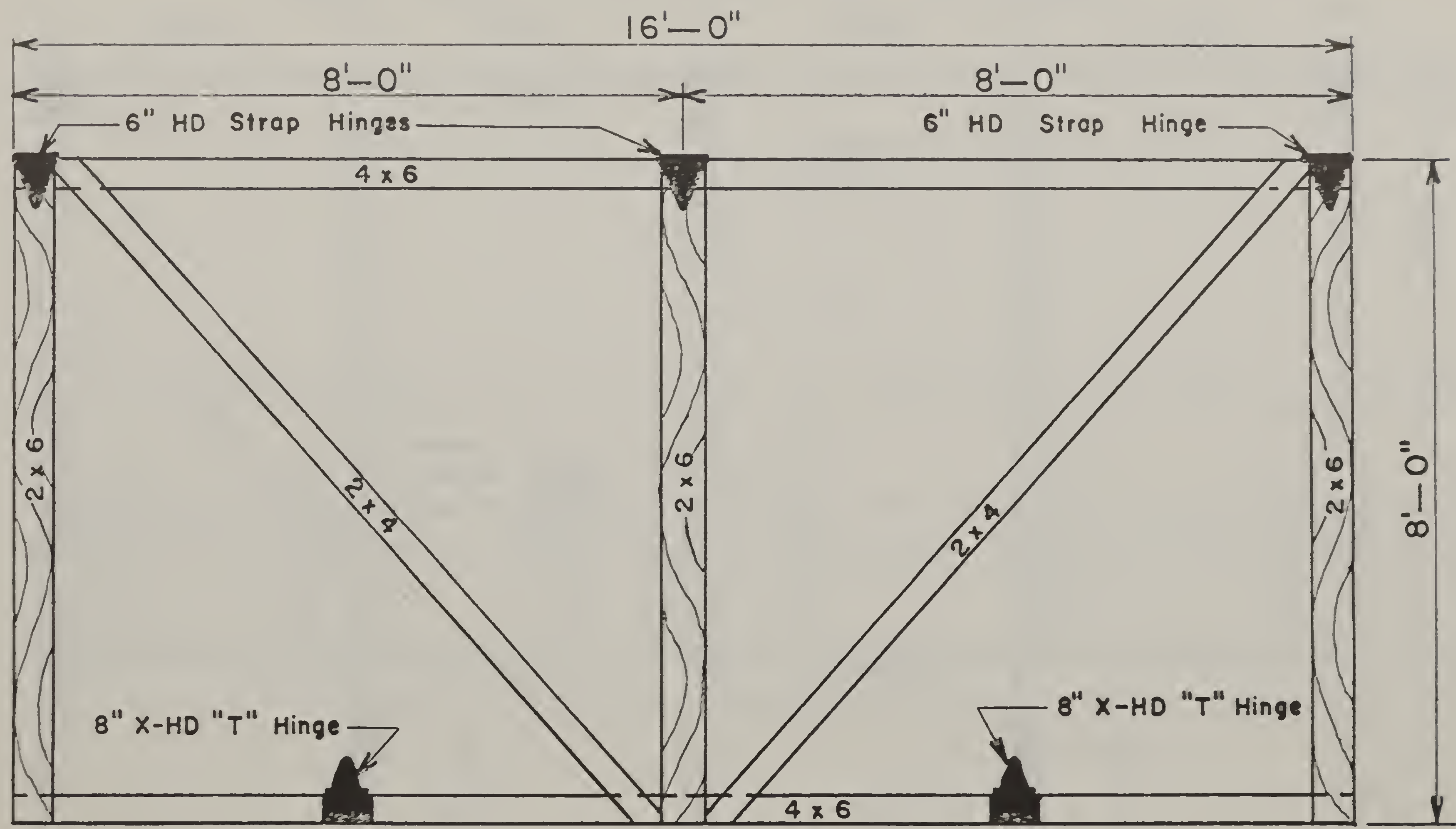
FRONT VIEW OF COLLECTOR



COLLECTOR'S SECTION A—A



REAR VIEW & FRAMING OF COLLECTOR



PLAN VIEW OF COLLECTOR'S SKID

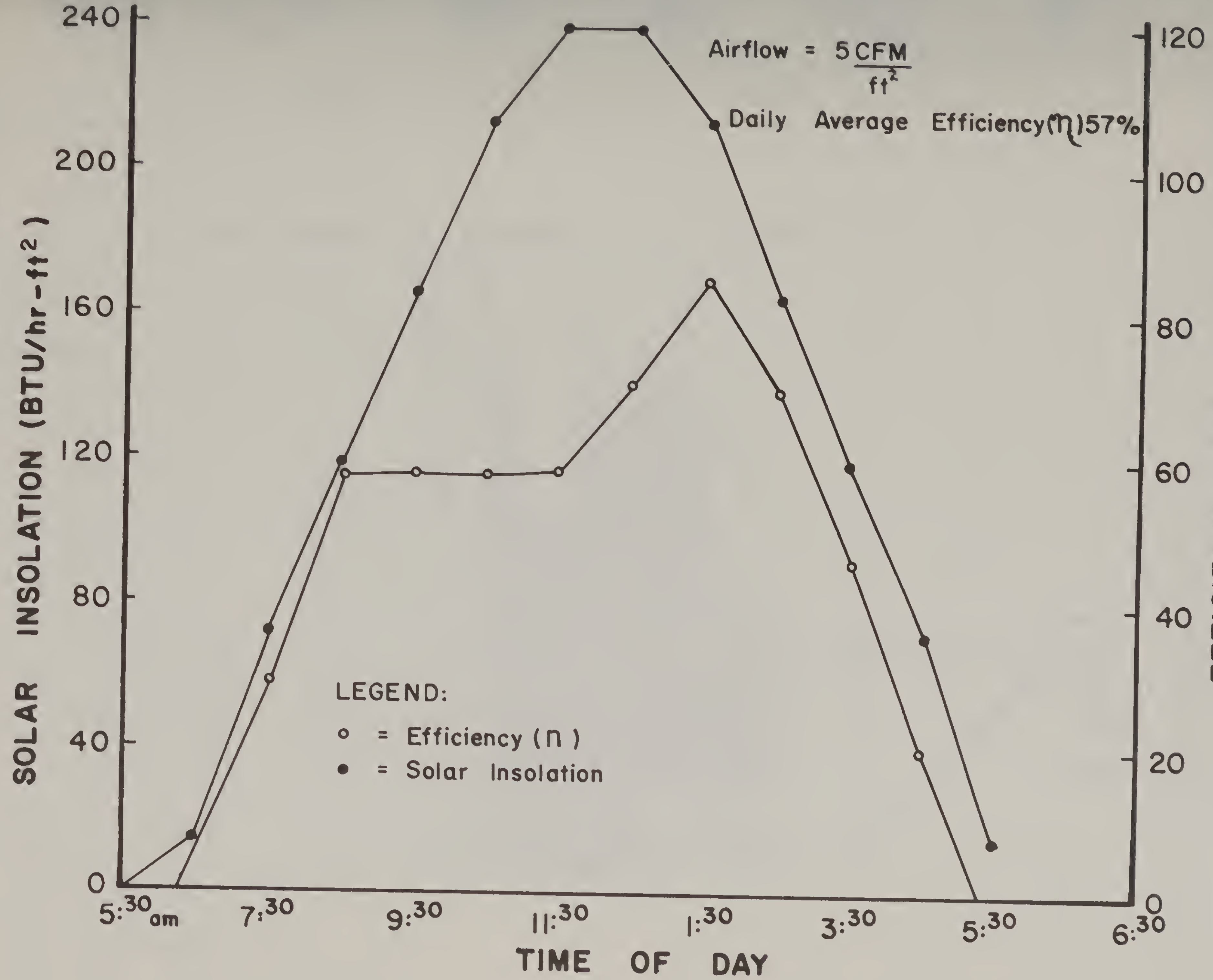


Figure 2: Typical day collector performance at Serenity Farm.

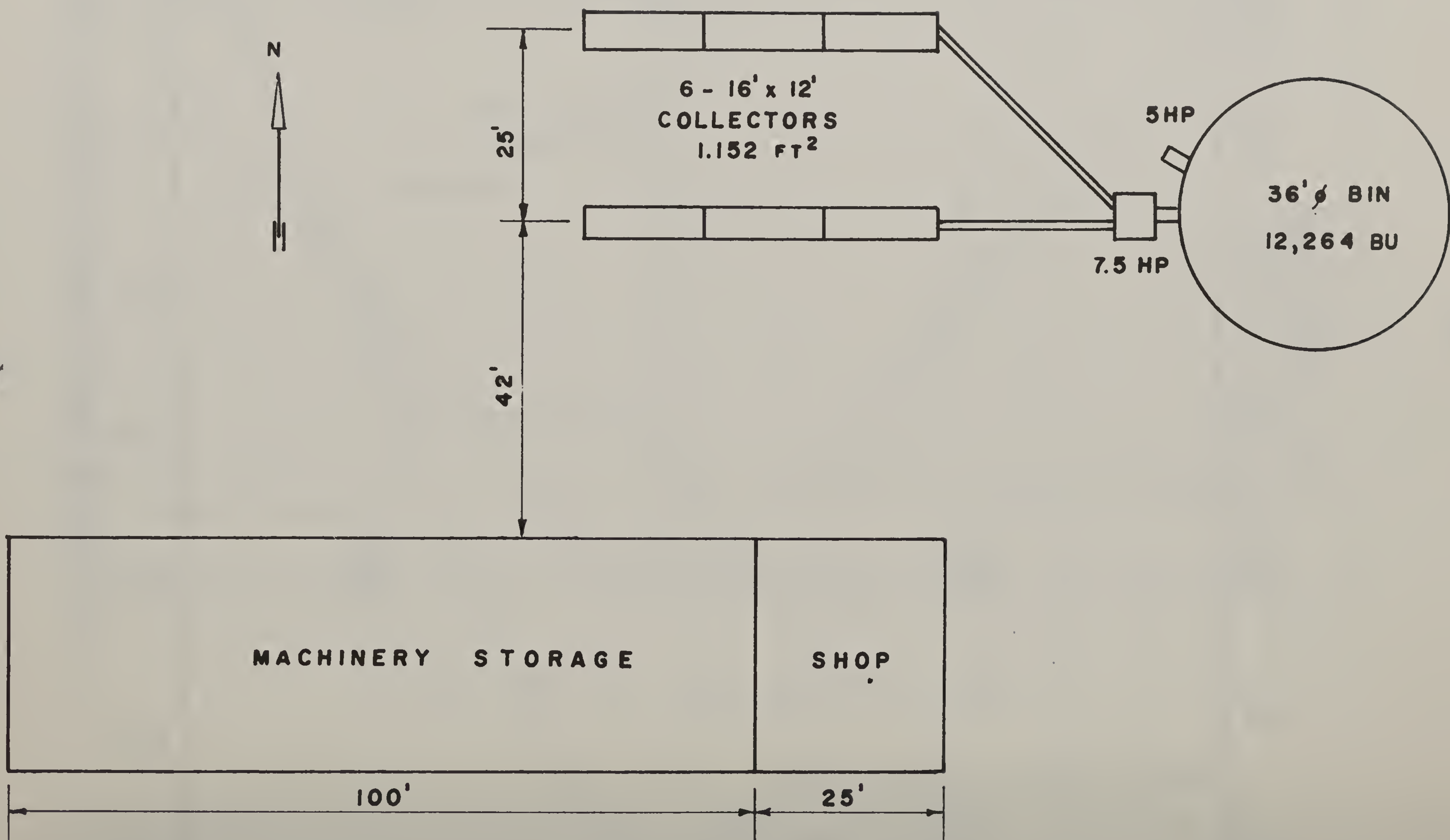


Figure 3. Layout of the Serenity Farm solar system.

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FACTS 140
December 1982

The Schoonover Farm Solar Grain Drying Demonstration

by

Larry E. Stewart, Chairman and
Gerald E. Berney, Faculty Extension Assistant
Department of Agricultural Engineering

Description of the Farm

Cool Spring Farm, Inc., is a father-son enterprise operated by James and Gary Schoonover. The Schoonover Farm is located on Whiteleysburg Road (Route 314) about one mile from Greensboro, Maryland, near the center of Maryland's Eastern Shore. The farm is about 8 miles north of Denton, the county seat of Caroline County. The farm is just 30 miles due east of the Chesapeake Bay Bridge.

The Schoonover Farm is a 500-acre grain and broiler farm. Approximately 300 acres of corn and 200 acres of soybeans are produced annually. This year 140 acres of soybeans will be double-cropped following barley. The Schoonover's produce nearly 100,000 broiler chickens annually in a 42 ft. by 404 ft. broiler house.

The current drying system consists of a 100-bushel-per-hour dryer (Super B) commonly operated at high temperatures (210°F). Two storage bins are in place; one is 36 feet in diameter by 24 feet (approximately 20,000 bushels) equipped with a 9.5 HP fan; the second is 27 feet in diameter by 18 feet 4 inches high (8,500 bushels) and is equipped with a 9 HP fan. Fuel and energy requirements for the system as currently operated are .215 gallons per bushel of LP gas and .1 kwhr per bushel of electricity to dry at a rate of 100 bushels per hour.

This project added a solar system into a combination drying program for the farm. The Super B dryer was utilized to dry the grain from 26 to 19.5% moisture (wet basis) and then low temperature solar energy was used to complete drying to 15.5% moisture.

This farm is a well managed father-son operation in an excellent location to demonstrate the optimal effects of management and solar systems on energy conservation.

Goals and Objectives

1. The major objective at this site is to demonstrate the energy and economic effectiveness of combination high and low temperature grain drying, with a solar system supplying the energy for the low temperature portion.

2. Specific goals are to:

   a. Change the management of the grain drying system from high temperature to combination drying.
   b. Design a cost and energy effective portable solar system that can be used for low temperature grain drying and to provide broiler brooding heat.
   c. Have the farmer construct the system.
   d. Monitor construction and operating costs.
   e. Monitor energy use for drying and brooding.
   f. Evaluate the energy and cost effectiveness of the system.
   g. Prepare a publication on the results of the project.
   h. Conduct field days or tours to demonstrate the system for interested farmers.

Solar System Design

A skid-mounted solar collector, closely patterned after the Purdue design (Figure 1) was the basic element of the solar system. Each collector has face dimensions of 12 feet high by 16 feet wide. The cover material is a single thickness of .04 inch FRP. The receiver is black-painted corrugated sheet metal and located 1.5 inches behind the cover with the corrugations in a vertical configuration. Another 3.5 inches

air passageway is provided behind the receiver and the back is constructed of 1/2 inch plywood reinforced with 2 by 4 wood ribs. No insulation was added to the backing for grain drying but can be added to panels as needed when the panels are diverted to alternate uses. The tilt of the panels can be manually adjustable by moving pins in a sliding pipe brace but only one position was used for the entire drying season. Three panels (576 sq. ft.) are used with the 36 feet bin.

Groups of panels were serially joined together by a wooden clamping system that could be vented if necessary. Air was drawn horizontally across the receiver. The air movement was provided by the existing fans. a 500 fpm face velocity that is recommended for the Purdue collector was maintained.

The alternate use for the collectors during the winter season will be to heat the broiler house during the brooding season, if the solar units are relocated or ducting is provided.

System Construction Costs

The 576 sq. ft. of solar collector and ducting were constructed by the Schoonovers. Costs of construction were as follows:

Materials Costs	\$2,233.10
Labor (318 hrs @ \$4/hr)	1,272.00
Total	\$3,505.10

Thus the average cost per square foot of collector, including ducts, was \$6.08.

System Performance

Solar radiation was measured with an Eppley B&W pyranometer and a Licor millivolt integrator. The pyranometer was mounted at the same slope as the collector face. Measurements for a "typical day" were based on hourly integrated values.

The thermal performance of the solar collector was evaluated for a typical day during the drying season. The energy output of the system was calculated using the measured values of air flow and critical temperatures. Because relative humidity and barometric pressures were not recorded on site, a constant specific heat (.24 Btu/lb) and a constant volume/mass ratio (14 ft^3/lb) were assumed. Hourly and full day efficiencies were calculated by dividing the energy output by the solar energy incident on the collector surface.

Typical day collector performance for the Schoonover collectors is shown in Figure 2. Solar insolation received and collector efficiency are indicated. The daily average efficiency for this unit was 89 percent.

In this first drying season with the solar system the Schoonovers dried 32,400 bushels of grain from 20 to 14 percent moisture. Forty

days were required for drying the grain at an average cost of 8.09 cents per bushel. The solar system provided 46.9 million Btus of energy which is equivalent to replacing 539 gallons of LP gas. Purchased energy per pound of moisture removed was 848 Btus per pound, which is approximately one-half the previous year's requirement.

System Payback

Based on one year's experience it appears that the solar system can be expected to save one gallon of LP gas for each square foot of collector surface. Assuming the cost of LP gas to be $.75 per gallon, the simple pay back period for the system will be $6.08/.75 equals 8.1 years.

This estimate does not take into account expected increases in cost of LP gas or the energy savings that will accrue through other uses of the system. Also energy tax credits are not considered in this calculation.

Operational Problems, Corrections and Other Management Factors

1. Dust and "beeswings" from the grain accumulate on the collector surface. The Schoonovers have developed a long-handled "squeegee" device to clean the surfaces.

2. The Schoonover system is a combination high temperature batch/in-bin solar system. It has been difficult to adjust the high temperature dryer to produce grain dried to exactly 18-20 percent moisture. This factor leads to the possibility of moisture gradients within the bin used for solar drying.

3. Some management changes are necessary for farmers moving from high temperature to low temperature solar drying:

   a. Grain entering the solar bin must be clean. The Schoonovers have had problems with an accumulation of fines and other debris in the center of the bin.
   b. Grass surface must be level for uniform air flow. This practice will need to be used at the Schoonover farm.
   c. Fans must be operated continuously once grain is placed in the bin.
   d. Harvested grain must be placed into the dryer as soon as possible. Schoonovers experienced some spoilage on grain that was held on a truck overnight before beginning drying.
   e. The mixing box at the fan inlet must allow a mixing of solar heated and natural air to control air flow over the collector surface. This has been a problem with the Schoonover unit.

Summary

The Schoonover farm will be an excellent demonstration of low temperature solar drying in combination with a high temperature drying unit. The energy saving potential is quite high. As the operators gain additional experience in managing the system, full potential energy savings will be realize.

To simplify descriptions, trade names of equipment and materials have been used. No endorsement is implied, nor is discrimination against similar products intended.

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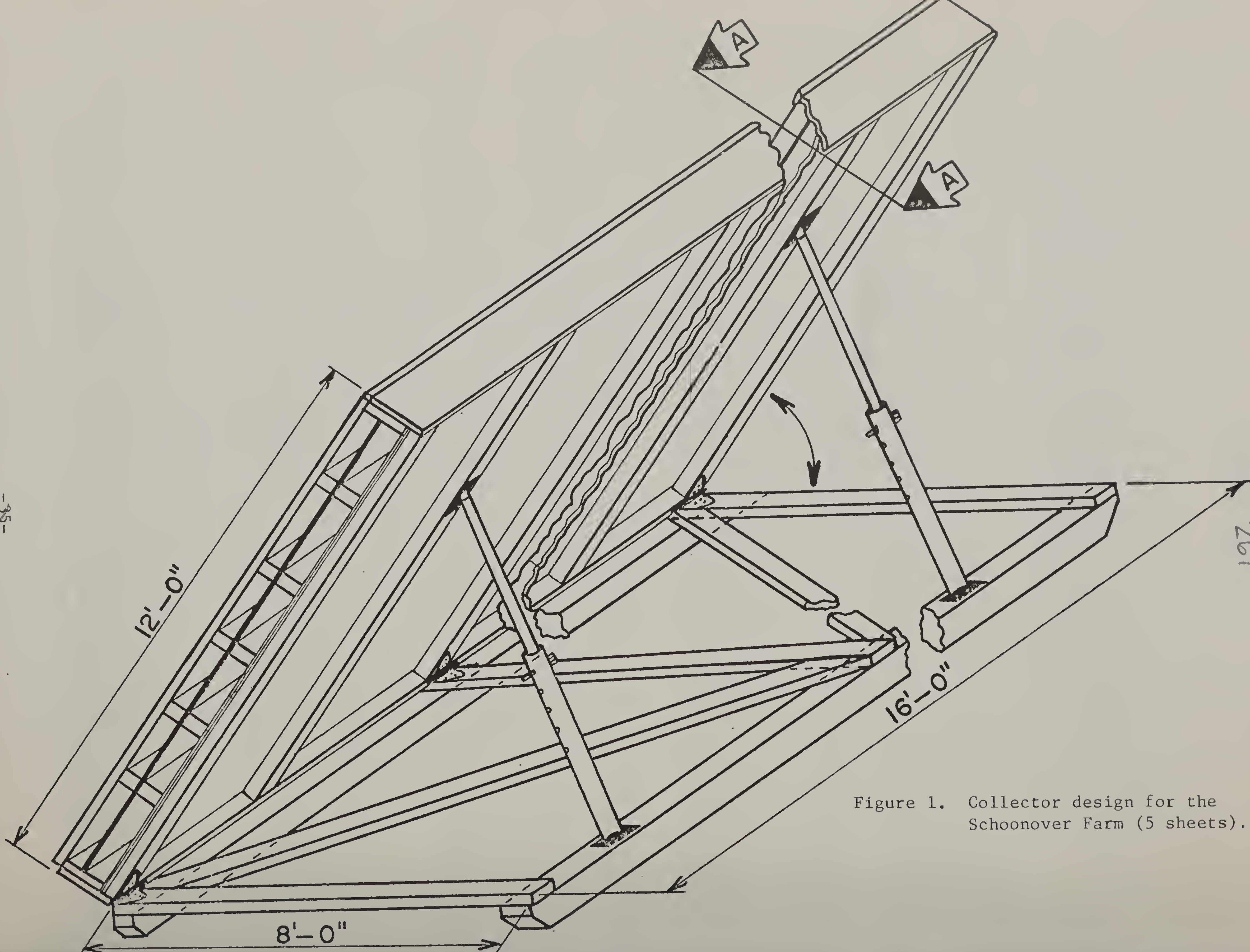
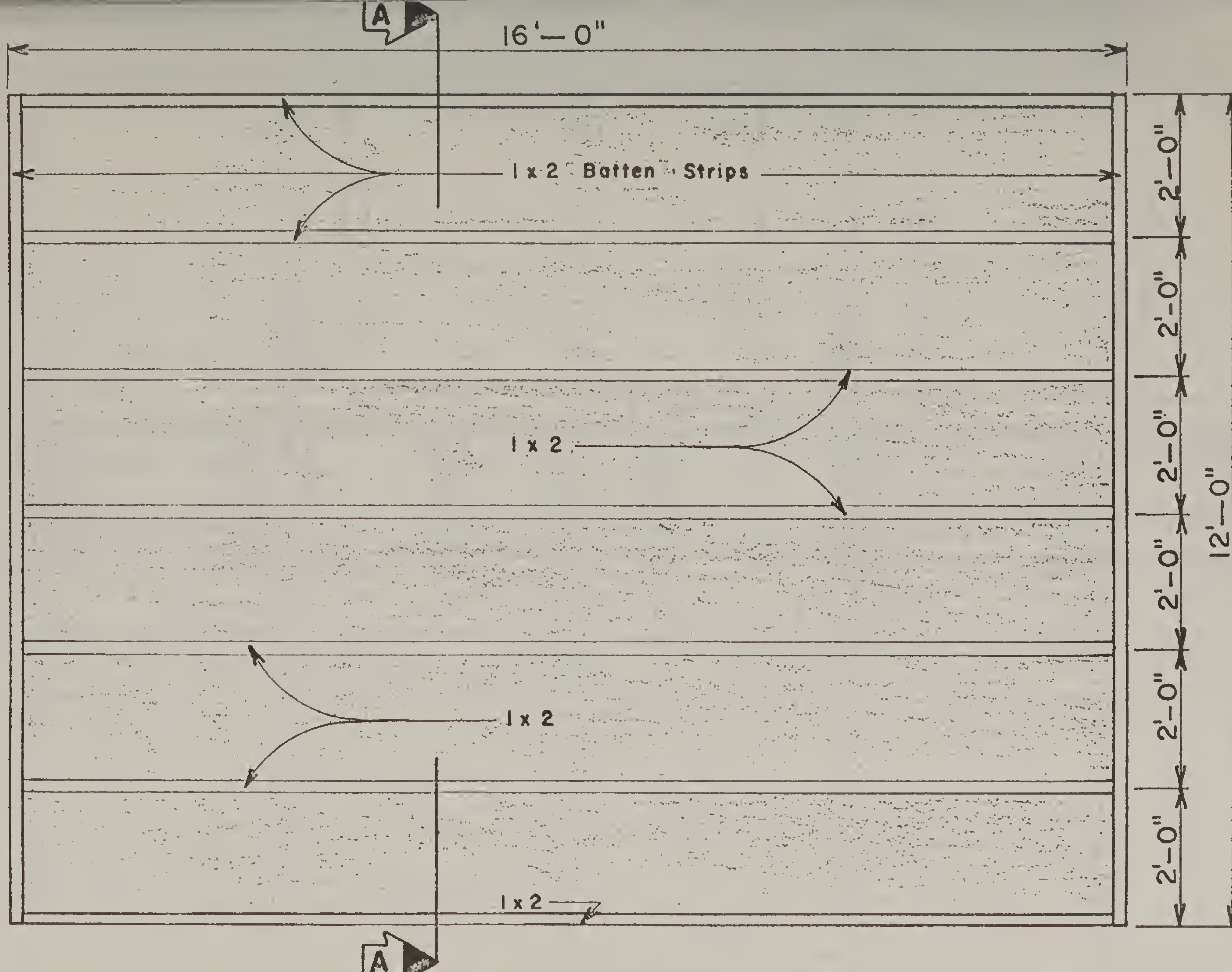


Figure 1. Collector design for the Schoonover Farm (5 sheets).

PORTABLE SOLAR COLLECTOR



FRONT VIEW OF COLLECTOR

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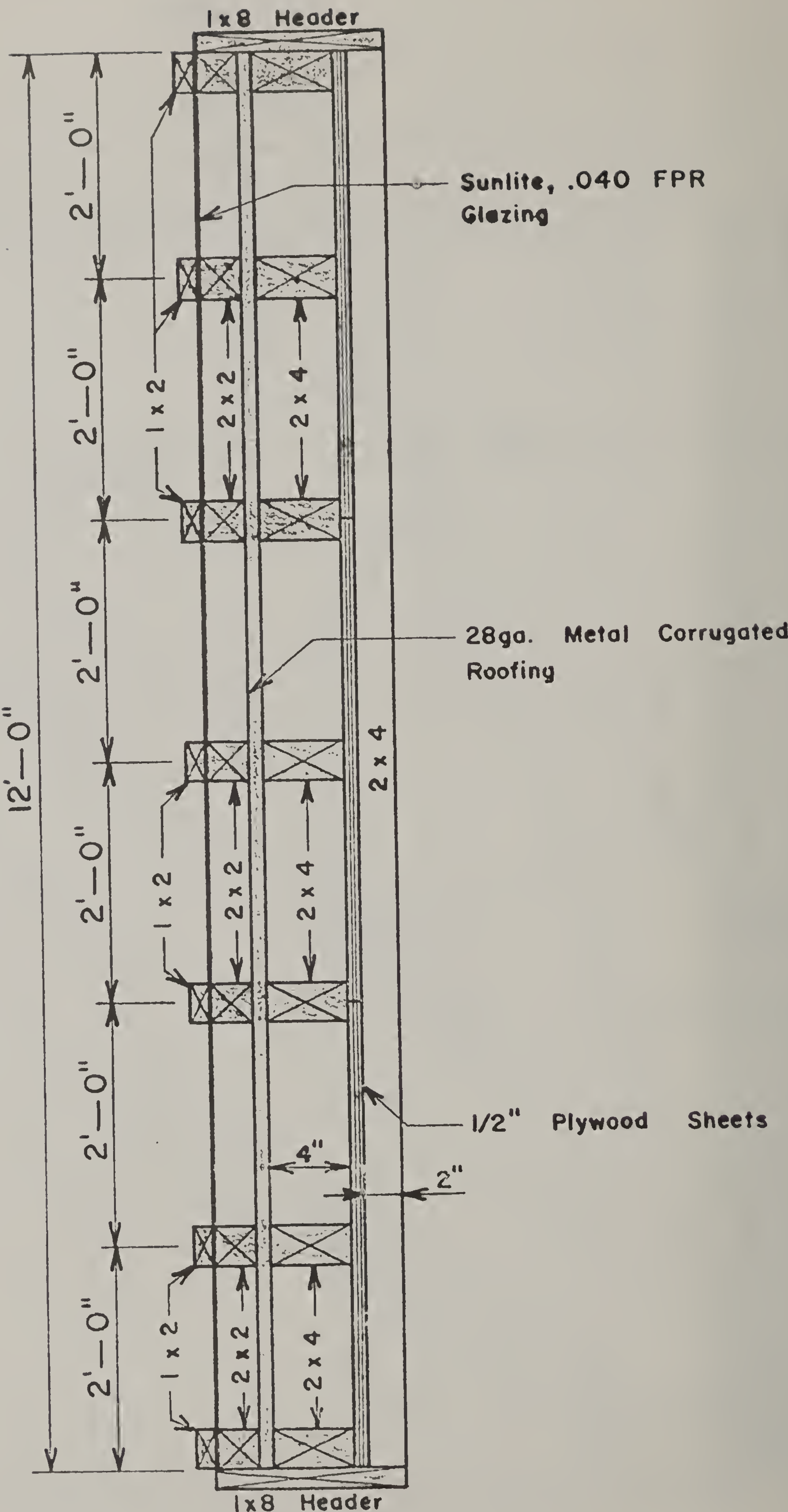
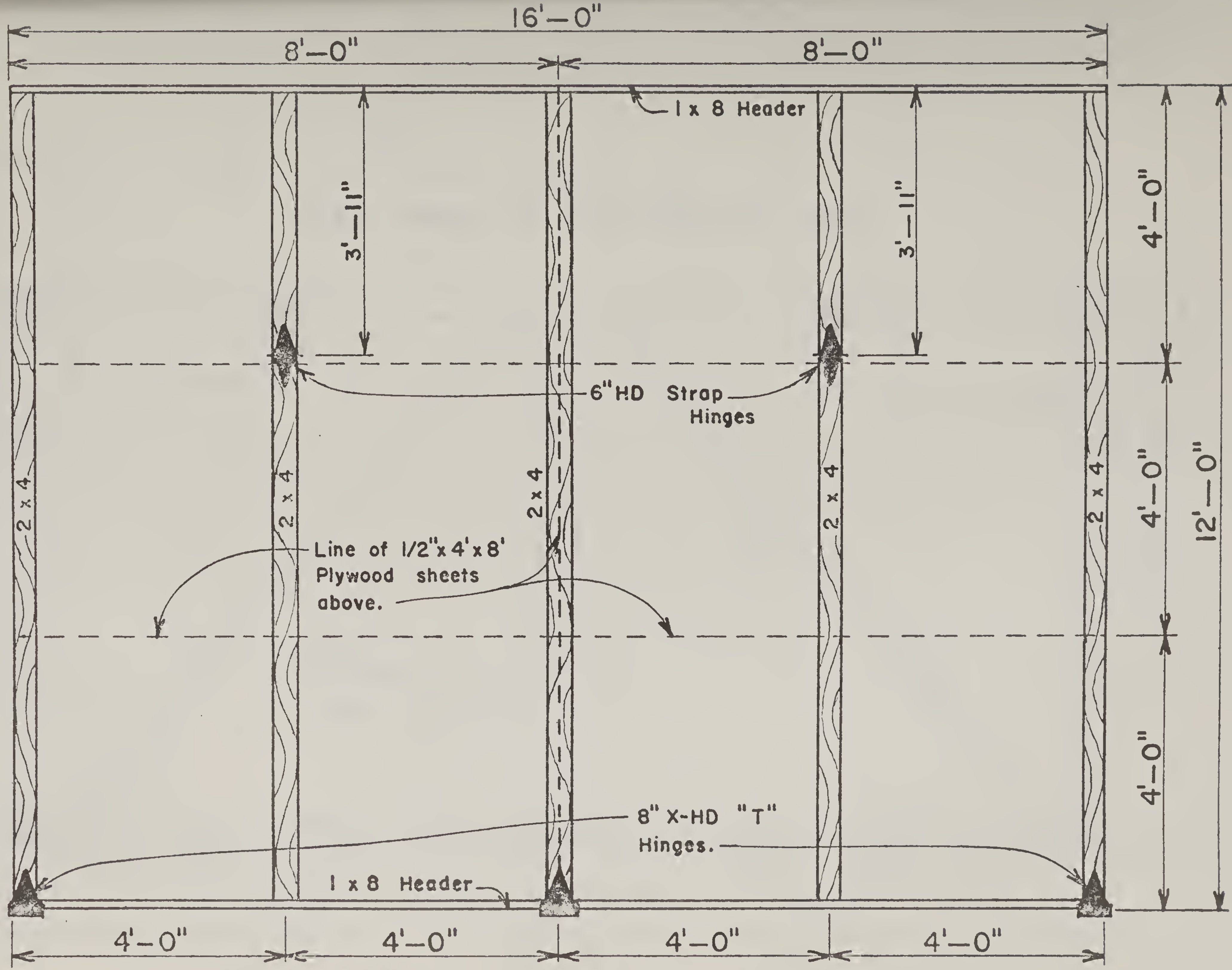
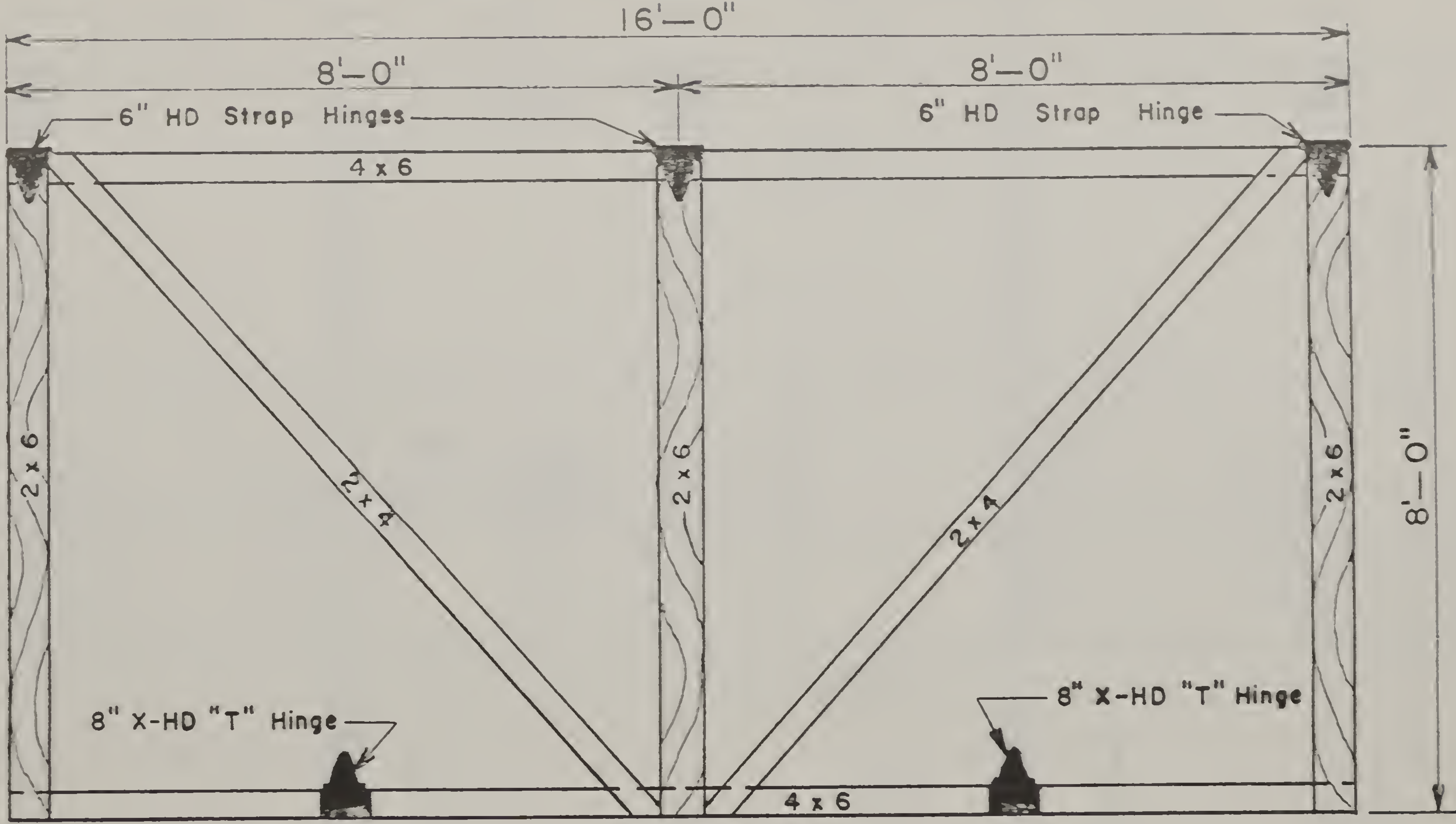


COLLECTOR'S SECTION A-A



REAR VIEW ¢ FRAMING OF COLLECTOR



PLAN VIEW OF COLLECTOR'S SKID

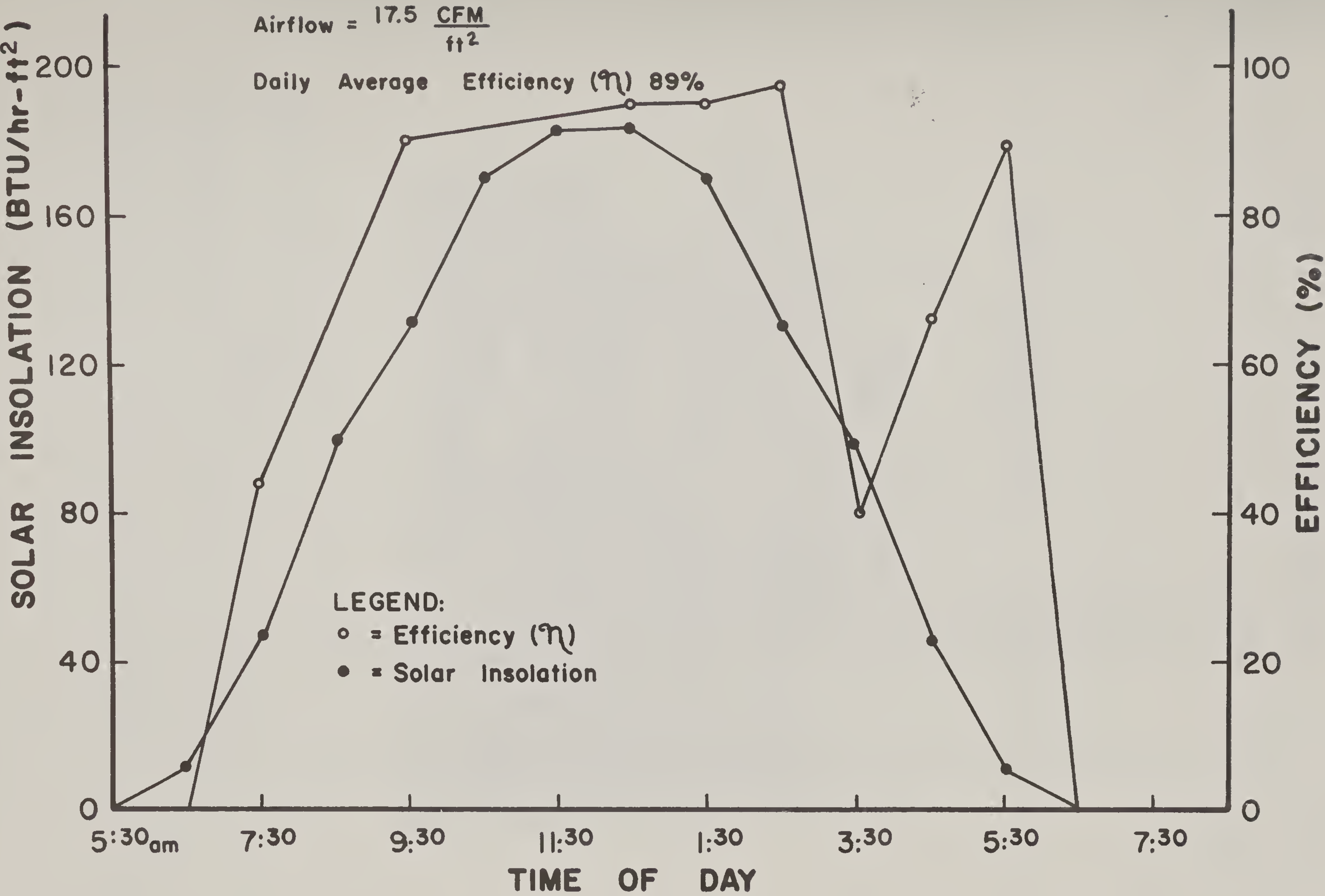


Figure 2. Typical day collector performance at the Schoonover Farm.

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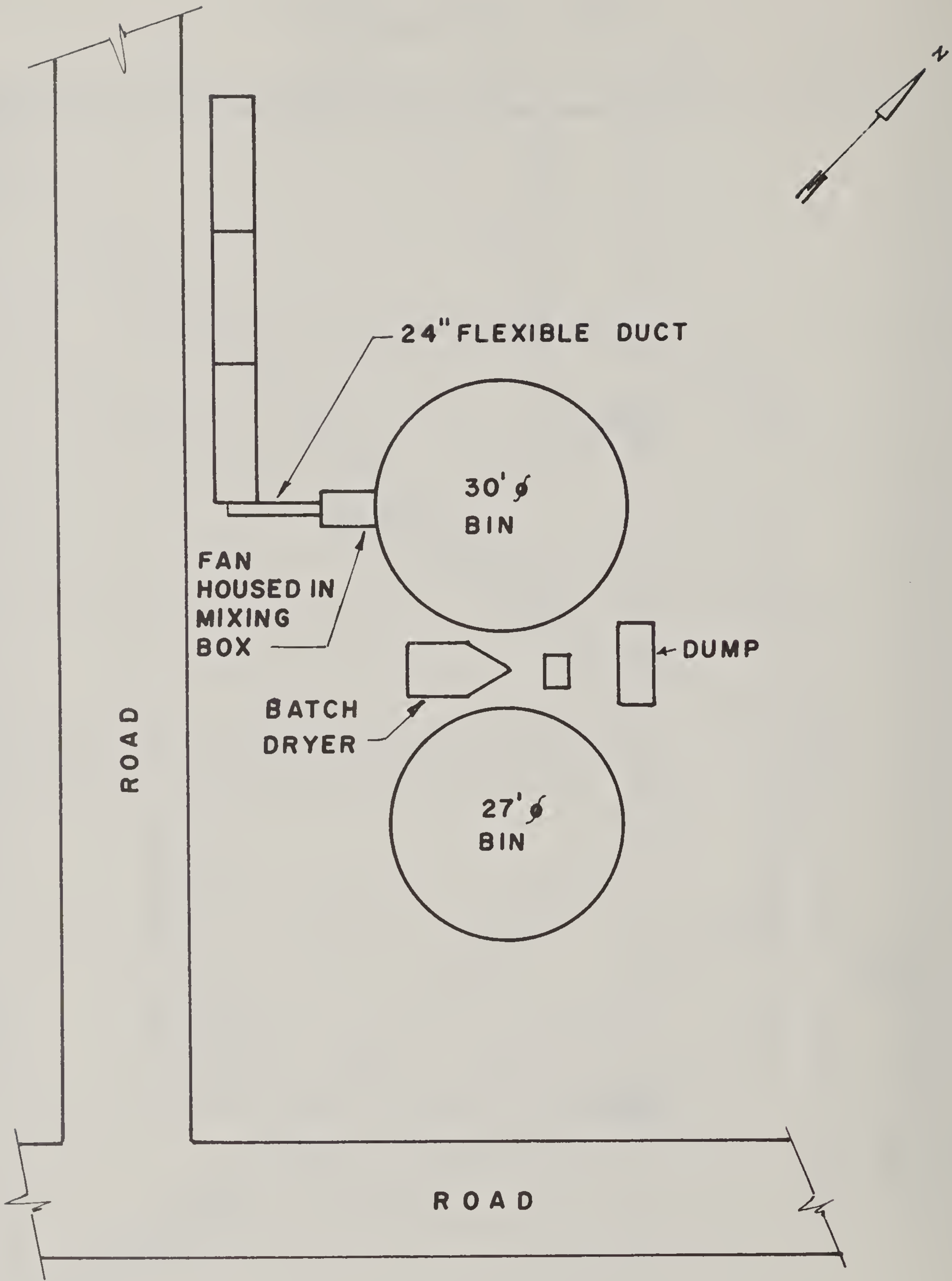

Figure 3. Grain drying facilities and solar collector at the Schoonover Farm.

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FACTS 141
January, 1983

The Price Farm Solar Grain Drying Demonstration

by
Larry E. Stewart, Chairman and Gerald E. Berney
Faculty Extension Assistant, Department of Agricultural Engineering

Description of the Farm

The Leon Price Farm is located about 2 miles north of Sharpsburg, Md., near the Potomac River just west of the Appalachian Trail in the Blue Ridge Mountains. The farm is a dairy-grain operation. It has a herd of about 50 cows in milk and harvests about 13,000 bushel of corn annually. The grain is dried in 2 - 24 ft. diameter x 20 ft. high bins using a 10 HP blower and a 1,300,000 Btu/hr. burner. A third bin, 36 ft. x 24 ft. high is used for storage. The farm is representative

of those in the Appalachian foothills and is well located as a demonstration project for Appalachian farmers. One of the drying bins is well suited for a wrap-around collector - a design that might well suit the tight economy of Appalachia.

Goals and Objectives

1. The objective is to demonstrate the practicality of a solar grain drying system to farmers in the Mid-Atlantic region.

2. Specific goals are to:
   a. Design the most cost-effective solar facility and drying management system that fits the needs of the Price Farm and Appalachia.
   b. Have the farmer construct the system.
   c. Monitor costs - construction and operating.
   d. Monitor drying effectiveness.
   e. Evaluate the cost-effectiveness.
   f. Conduct field days or tours to demonstrate the system for interested farmers.

Solar System Design

A 24 ft. diameter drying bin was fitted with a wrap-around collector as shown in Figure 1. Some unique construction modifications were made in the design to reduce air flow restrictions between the cover plate and and the black solar collection surface. Vertical lath strips were bolted to 4 inch steel channel sections which, in turn were welded to the bin wall. This design greatly simplified construction and reduced the labor requirements for the installation.

The cover plate used was a single layer of 0.040 in FRP sheets, also vertically installed. A second wood lath was used to cover the joints at the edges of the cover plate.

The collector surface was prepared by cleaning and then painting with a flat black paint. A transition section from the wrap-around to the fan housing was developed to minimize air flow restrictions and to provide uniform air flow across the collector surface.

A duct and fan housing was constructed to duct heated air from the collector to the drying fan. The rate of air flow through the collector can be modified as needed by adjusting a sliding vent door at the bottom of the fan housing.

In operation, the solar radiation transmitted through the FRP sheets heats the black painted steel walls of the grain bin. Some of this heat is directly transmitted to the grain immediately behind the receiver and provides some of the needed supplemental heat. However, most of the heat absorbed by the receiver is carried by the air that flows between the FRP and the collecting surface to the intake of the fan for pumping into

the grain mass. The total solar collector area is 1200 square feet.

No alternate uses of the wrap-around collector are planned, but it would be possible to duct heat into a nearby farm shop.

System Construction Costs

The 1200 square feet of solar collector and ducting were constructed on the farm with farm labor. Costs of construction were as follows:

Materials Costs	$2348.89
Labor (216 man hours @ $5.00)	1080.00
Total	$3428.89

Thus the average cost per square foot of collector was $2.85.

System Performance

Solar radiation was measured with an Eppley BTW pyranometer and a Licor millivolt integrator. The pyranometer was mounted on a horizontal surface and readings were corrected for the actual orientation of the collector. Measurements for a "typical day" were based on hourly integrated values.

The thermal performance of the solar collector was evaluated for a typical day during the drying season. The energy output of the system was calculated using measured values of air flow and critical system temperatures. Because relative humidity and barometric pressure were not recorded on site, a constant specific heat (.24 Btu/lb) and a constant volume/mass ratio (14 ft^3/lb) were assumed. Hourly and full day efficiencies were calculated by dividing the energy output by the solar energy incident on the collector surface.

Typical day collector performance for the Price Farm collector is shown in Figure 2. Solar insolation received and collector efficiency are indicated. The daily average efficiency for the Price unit was 48 percent.

In this first drying season, 8300 bushels of corn were dried from 24.0 to 15.1 percent moisture (wet basis). Twenty-one days were required for drying the grain at an average cost of 12.3 cents per bushel. The solar system provided 15.4 million Btus of energy which is equivalent to replacing 178.1 gallons of LP gas. Purchased energy per pound of moisture removed was 1075 Btus per pound.

System Payback

Because the collector was available for only a portion of the drying season and mechanical problems occurred with the stirring augers, it is necessary to extrapolate expected economic returns to the farm. Assuming

the system will be fully utilized in subsequent years, it is believed that annual LP gas savings will reach 700 gallons or about .6 gallons per square foot of collector per year. Assuming the cost of LP gas to be $.75 per gallon, the single pay back period will be:

$$\$2.85/.6 \times \$.75 = 6.3 \text{ years}$$

This estimated pay back period does not take into account energy tax credits, expected increases in costs of LP gas or energy savings that may accrue through alternate uses of the system.

Operational Problems, Corrections and Other Management Factors

A breakdown in the stirring auger system caused the farmer to operate his LP gas dryer on the first batch of corn placed during this study. This problem significantly reduced the energy savings potential of the solar system. However, adjustment of the air flow through the collectors and repair of the stirring augers allowed drying the remainder of the grain without the use of LP gas.

A comparison of the two batches indicates that the solar system operates much more efficiently when used as the primary heat source.

One other problem was evident. Dust and grain bees wings accumulated on the wire screen at the air inlet to the collector and also on the inside surface of the cover plate. Most of the small particles on the inside of the collector are from drying soybeans and perhaps the problem can be eliminated only by not placing soybeans in the system.

Summary

The wrap-around collector offers a low cost method of solar grain drying with reasonable efficiencies. Although additional experience with the system is needed, it appears to be a viable alternative for many small grain drying operators.

To simplify descriptions, trade names of equipment and materials have been used. No endorsement is implied, nor is discrimination against similar products intended.

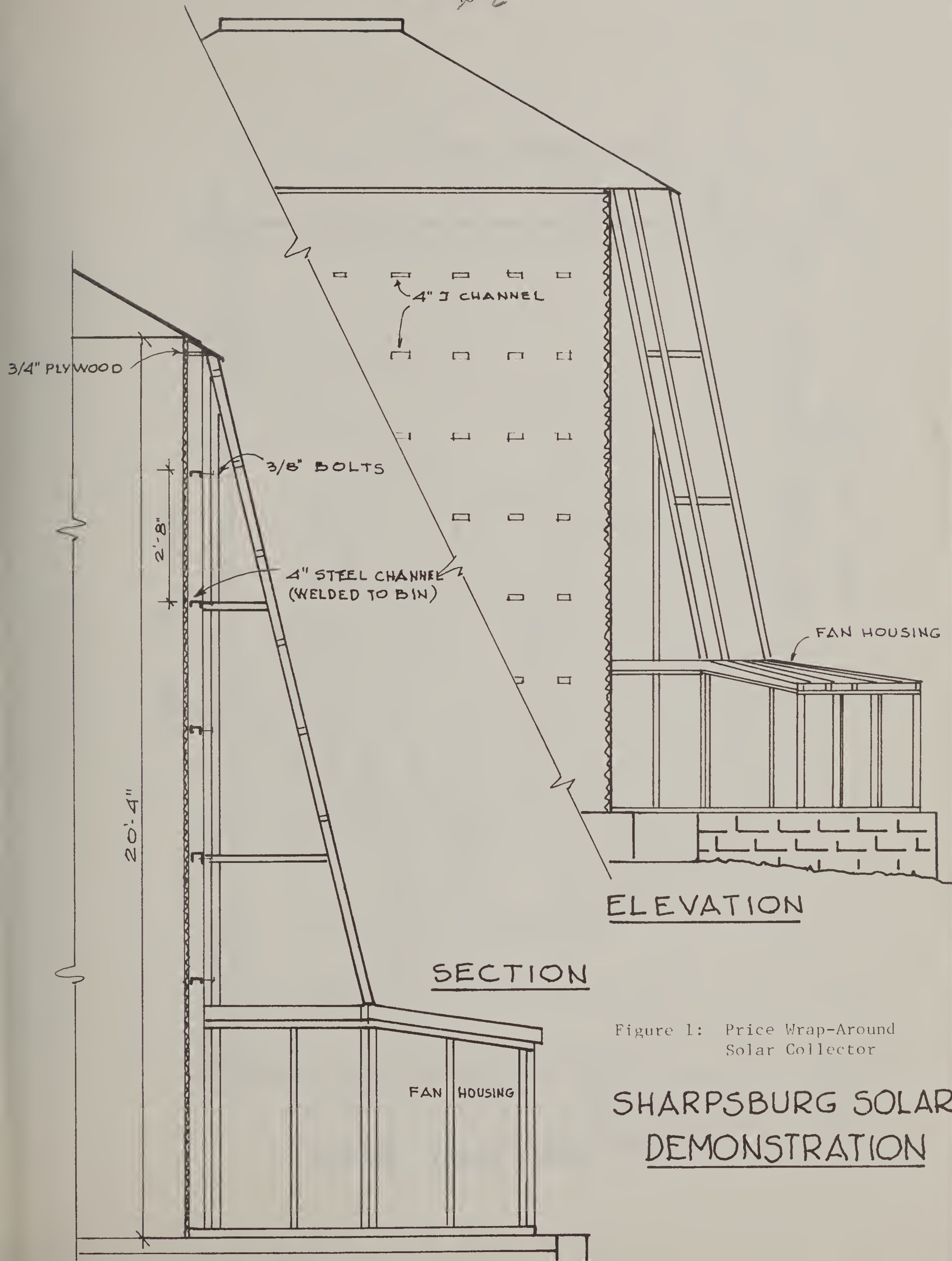

Figure 1: Price Wrap-Around Solar Collector

SHARPSBURG SOLAR DEMONSTRATION

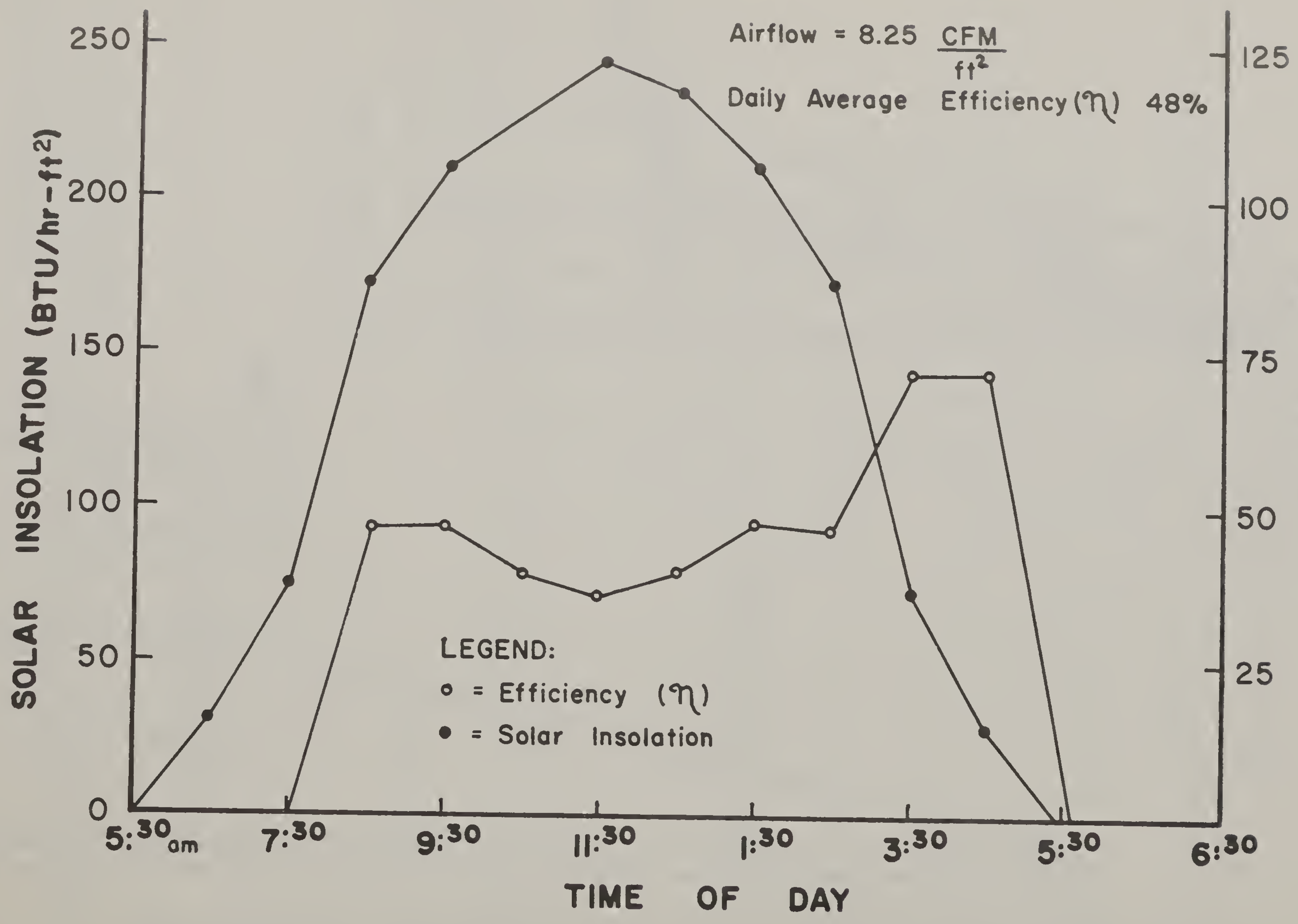

Figure 2: Typical dav collector performance at the Price Farm

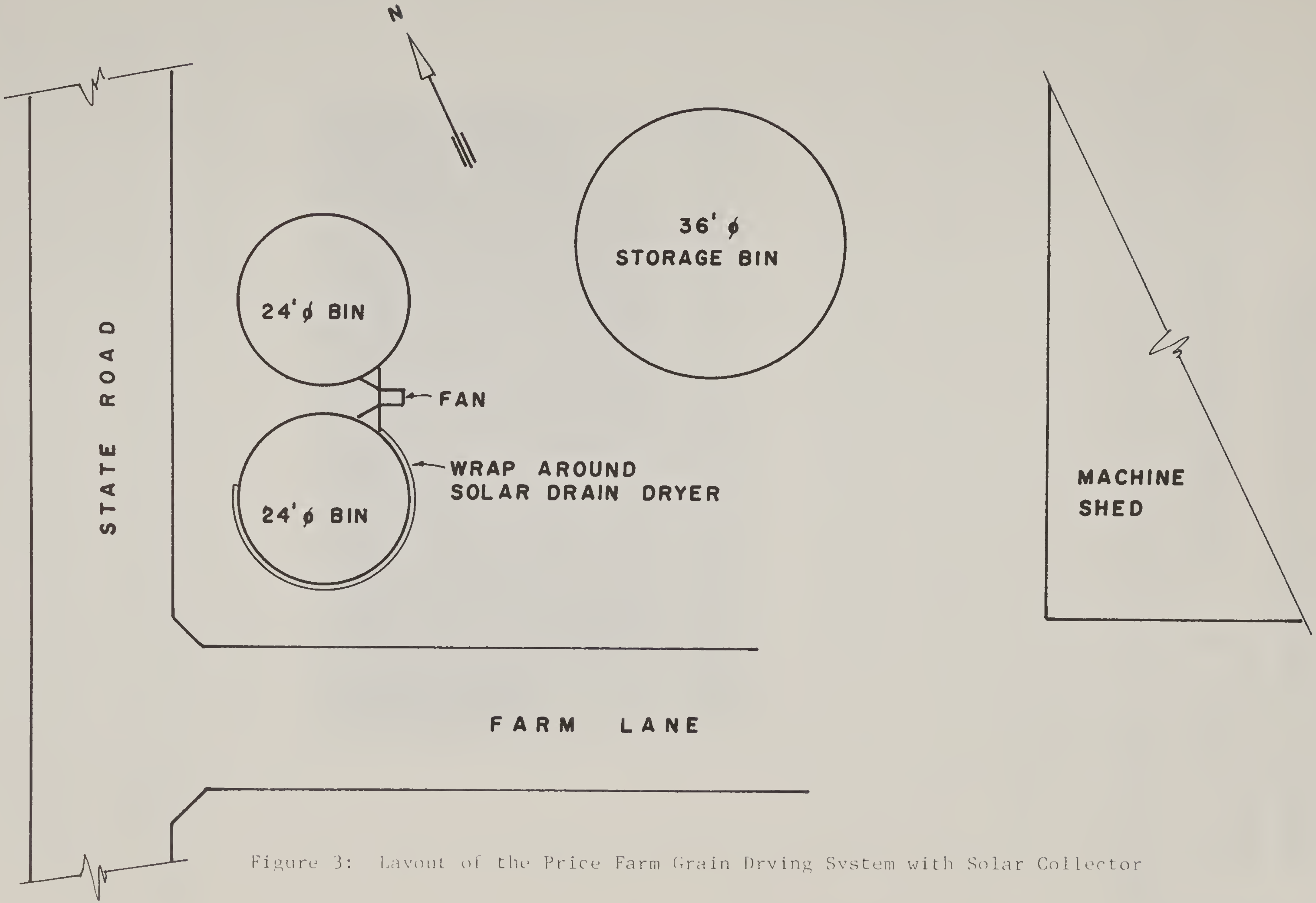

Figure 3: Layout of the Price Farm Grain Drying System with Solar Collector

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COLLEGE PARK, MD 20742

FACTS 142
December 1982

The Wilmot Farm Solar Hay Drying Demonstration

by

Larry E. Stewart, Chairman and
Gerald E. Berney, Faculty Extension Assistant
Department of Agricultural Engineering

Description of the Farm

Summit Hall Turf Farm is operated by Mr. Frank Wilmot of Gaithersburg, Maryland. The farm is located about 8 miles southwest of Gaithersburg, at the intersection of River and Mt. Nebo Roads, which is about 25 miles northwest of Washington, D.C.

The Wilmot farm is a hay and turf farm wherein alfalfa is grown for 4 years, herbicides applied, then overseeded with bluegrass to form sod. About 400 acres are devoted to this operation. He reaps 5 cuttings of

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excellent alfalfa per year. Mr. Wilmot has been experimenting with solar drying of his bales in a 11 ft. by 46 ft. drying structure and has had good success with drying from 30 percent moisture down to 10 percent or less. He has obtained premium prices for his artificially dried hay.

The site is on a gravel road but once on site, there is an excellent demonstration area around the collector. Mr. Wilmot is a progressive young farmer with an excellent engineering background and displays an excellent aptitude for monitoring solar systems. The system presents an opportunity to demonstrate the application of solar to hay drying.

Goals and Objectives

1. The objective is to demonstrate the practicality of solar hay drying system to farmers in the Mid-Atlantic region.

2. Specific goals are to:
   a. Modify the solar facility and drying management system.
   b. Have the farmer make the modifications.
   c. Monitor costs - construction and operating.
   d. Monitor drying effectiveness.
   e. Evaluate the cost-effectiveness.
   f. Conduct tours to demonstrate the system for interested farmers.

Solar System Design

The solar system consists of approximately 1400 sq. ft. of collector area. The drying facility itself forms the major support for the panels. Thus the uppermost 6 ft. of length has the same slope as the roof (about 45° from horizontal), the next 8 ft. of length is in the vertical mode, the next 17 ft. is at about 30° from the horizontal.

Air is drawn through the 30° section, through the other sections and through an attic plenum by 4 - 2 HP blowers. Each blower directs the air downward into one of the 4 - 11 ft. by 11 ft. bins. Hay bales are tightly stacked on edge in the bin to a depth of 12 ft. and the air exhausts through the slotted floor and outside through a plenum chamber beneath the dryer. For drying the preferred method is upward movement but the downdraft version fits well into the solar configuration. About 300 cfm/ton is provided.

The collector consists of corrugated aluminum roofing, painted black, with the corrugations perpendicular to air flow. Air flow flows through a 1.75 inch space on both sides of the receiver. The cover is 0.040 inch FRP sheet plastic and the back is plywood. The entrances to the collector have insect screens.

Hay is dried in batches 12 feet in depth that completely fill a bin.

System Construction Costs

The 1400 sq.ft. of solar collector were constructed on the farm with farm labor. Total cost of the solar system was $3,900. Thus the average cost per square foot of collector was $2.78.

System Performance

Solar radiation was measured with an Eppley B&W pyranometer and a Licor millivolt integrator. The pyranometer was mounted on a horizontal surface and readings were corrected for the collector orientation. Measurements for a "typical day" were based on hourly integrated values.

The thermal performance of the solar collector was evaluated for a typical day during the drying season. The energy output of the system was calculated using measured values of air flow and critical system temperatures. Because relative humidity and barometric pressure were not recorded on site, a constant specific heat (.24 Btu/lb) and a constant volume/mass ratio (14 ft^3/lb) were assumed. Hourly and full day efficiencies were calculated by dividing the energy output by the solar energy incident on the collector surface.

Typical day collector performance for the Wilmot Farm collector is shown in Figure 2. Solar insolation received and collector efficiency are indicated. The daily average efficiency for this unit was 36.4 percent.

Approximately 150 tons of alfalfa were dried from 30 to 10 percent moisture during 1982. The solar system provided approximately 60 million Btus of energy for drying which is equivalent to 723 gallons of LP gas. Purchased energy per pound of moisture removed was 1330 Btus per pound.

System Pay Back

Assuming 1982 was a typical solar year, a simple pay back period for the solar system was 5.6 years. This estimate does not take into account expected increased costs of LP gas or energy tax credits available to the farmer.

Operational Problems, Corrections and Other Management Factors

The original collector was constructed in 1979. There are already signs of aging of the collector glazing and fiberglass "bloom" is evident.

A portion of the unit is insufficiently braced against wind loads and some damage has already occurred.

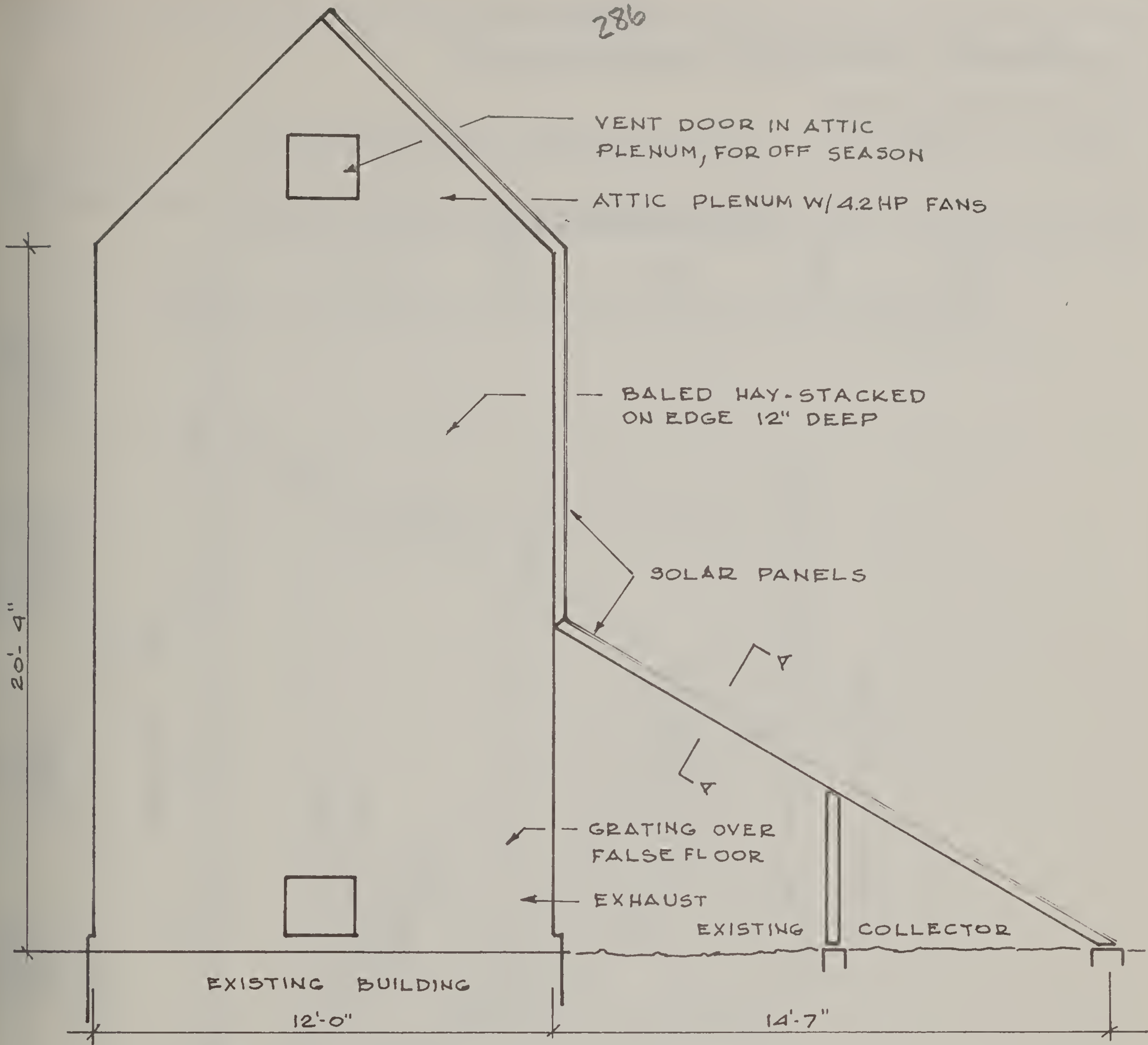
Spot molding of hay occurs occasionally in the batches. The exact cause of the problem is unknown. However it appears that the fan system is moving only about 300 cfm per ton of hay, which is below the 500 cfm per ton normally recommended.

The batch loading and unloading of the system is labor intensive. However the high quality of the finished product has netted the farmer about $10 per ton ($1,500 per year) after accounting for operating costs.

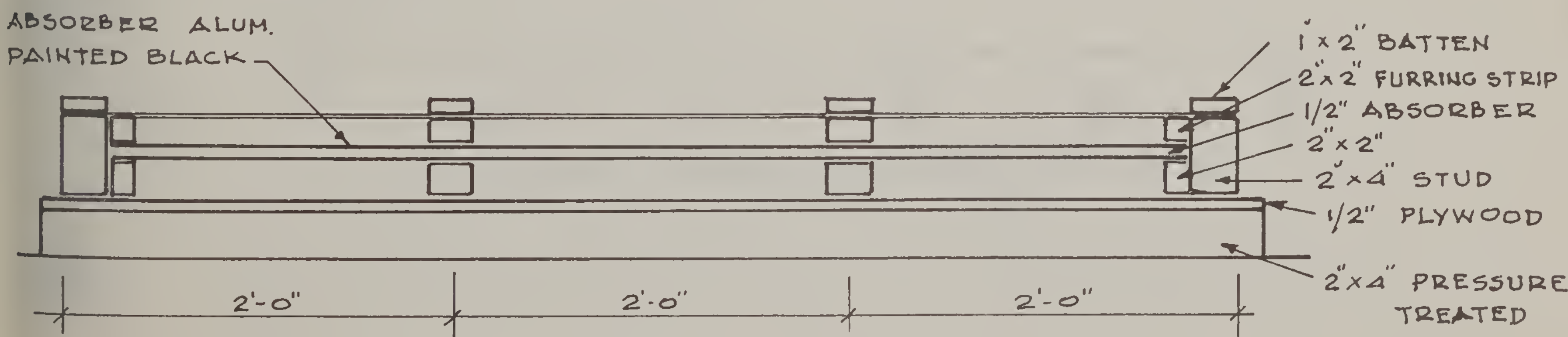
Summary

Experience in solar hay drying in Maryland is limited. Mr. Wilmot is to be commended for his effort and other Maryland farmers will greatly benefit from his experience.

To simplify descriptions, trade names of equipment and materials have been used. No endorsement is implied, nor is discrimination against similar products intended.



SIDE VIEW
1/4" = 1'-0"



SECTION A-A
1" = 1'-0"

Figure 1.

SUMMIT HALL SOLAR
HAY DRYER

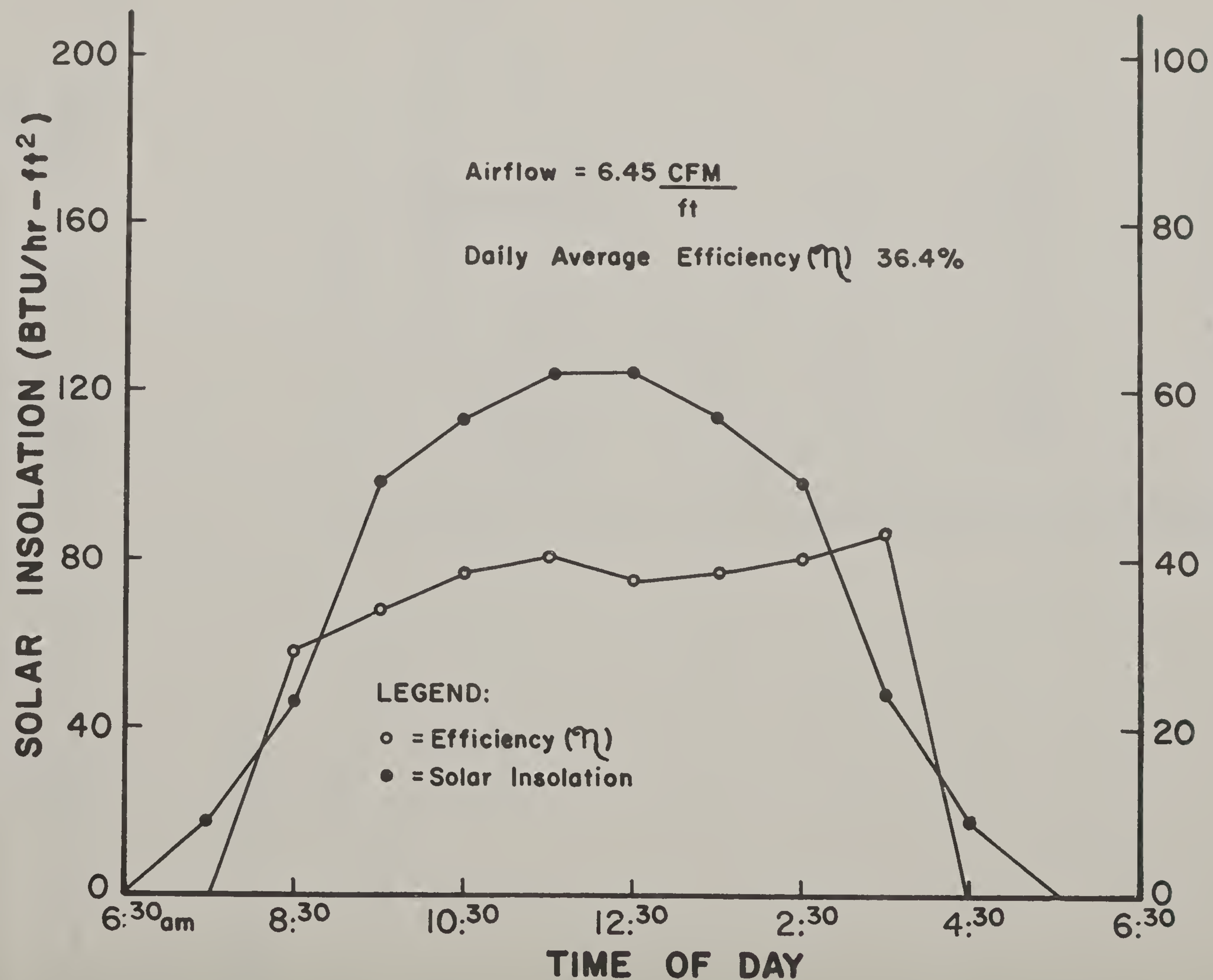


Figure 2. Typical day collector performance at the Wilmot Farm.

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Cooperative Extension Service

AGRICULTURAL ENGINEERING **FACTS**

UNIVERSITY OF MARYLAND-COLLEGE PARK — UNIVERSITY OF MARYLAND-EASTERN SHORE

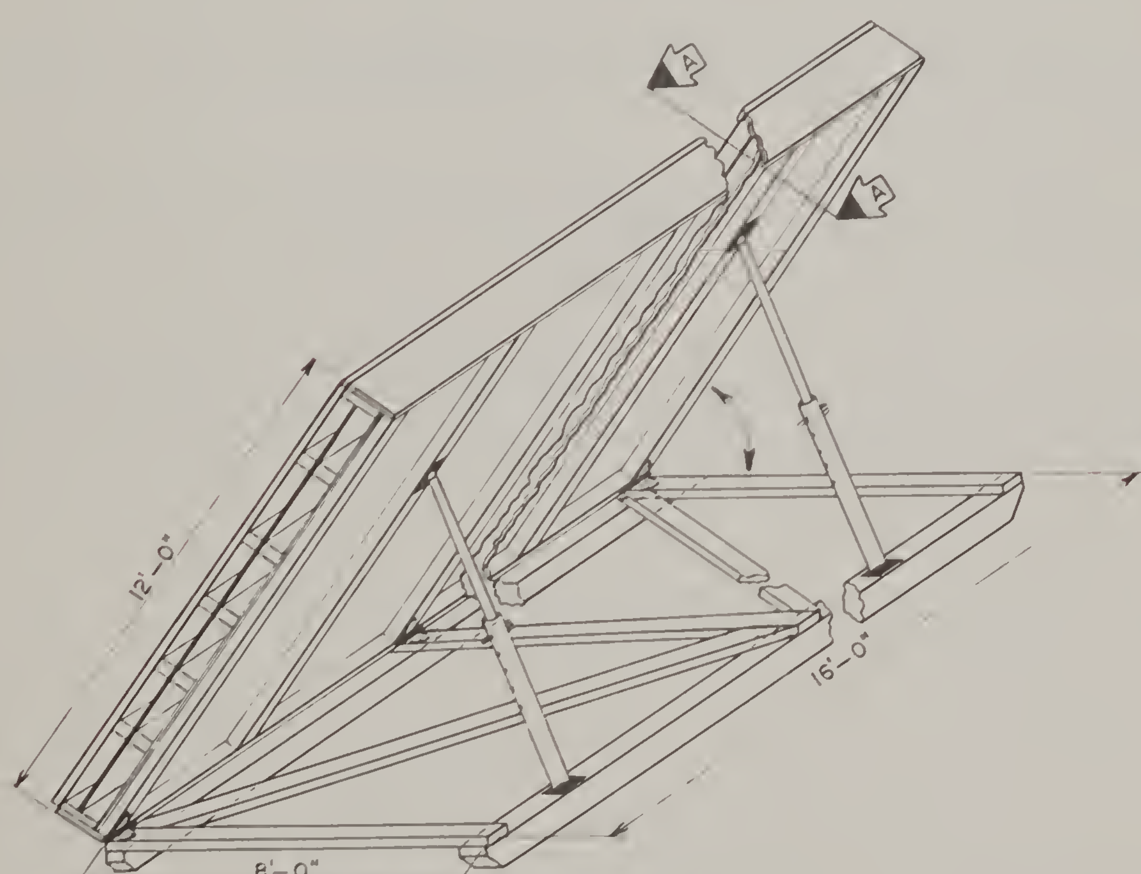
PREPARED BY SPECIALISTS — AGRICULTURAL ENGINEERING DEPARTMENT — UNIVERSITY OF MARYLAND
COLLEGE PARK, MD 20742

FACTS 143
December 1982

How to Construct a Portable Solar Collector

by

Gerald E. Berney, Faculty Extension Assistant and
Larry E. Stewart, Chairman
Department of Agricultural Engineering



PORTABLE SOLAR COLLECTOR

Low temperature solar grain drying systems provide a viable alternative for reducing purchased energy costs on many Maryland farms. Many types of designs of solar collectors are available that have application to existing grain drying systems. One such design is for a portable suspended plate collector. The design herein presented is an improved modified version of a collector developed by researchers at Purdue University.

The collector surface is 192 sq. ft. in area for each 12 ft. by 16 ft. module. As many as three modules can be placed in series for applications requiring larger collection surfaces. When needed, additional collectors can be placed in parallel rows, with appropriate ducting to direct heated air to the intake of the drying fan.

Cost of material for the unit in Maryland is \$3.50 - \$3.75 per sq.ft. and 75 - 100 man-hours of labor are required for construction. Thus total cost of construction per unit is \$5.50 - \$6.00 per sq.ft. or \$1000 - \$1200.

Under normal operating conditions, it is expected that the units will reduce purchased energy costs the equivalent of 1 gallon of LP gas per sq.ft. of collector in grain drying applications.

The information which follows outlines the tools and materials needed for construction of a 12 ft. by 16 ft. collector. A step by step procedure for building the unit is also described.

In addition, materials lists for constructing a plenum (air collecting chamber) and a mixing box for controlling air flow into the drying fan are provided.

Please note that it is necessary to anchor the collector so that it can withstand the effects of high velocity winds. A simple cable with ground anchor system is recommended.

Before constructing this or any collector, it is recommended that engineering advice be sought to provide a properly sized design for a specific grain drying system. Contact the local County Extension Agent to receive engineering help.

HOW TO BUILD THE SOLAR COLLECTOR

A. Tools

1. Drill (1/4" is adequate)
2. Bits: 1/4", 5/16", 9/64", 5/64", 3/16", 1/8"
3. Hammer
4. Wrenches: 1/4", 3/4"
5. Screwdriver

B. Materials

See Parts List for each sub-unit

C. The Collector

1. Lay out the 7 - 2"x4"x16's on edge, 2' on center
2. Nail the 6 - 4'x8' sheets of plywood with 6d nails 6" on center.
3. Lay out the 5 - 12' long 2"x4"s 4' on center.
4. Flip the collector over and place it on top of the 5 - 12'x2"x4" aligning them so that all joints in the plywood are supported.
5. Nail with 6d on 6" centers.
6. Drill holes for the 2 - 6" strap hinges and 3 - 8" tee hinges with 5/16" bit. Use the hinges for templates. (See drawings for location).
7. Insert 5/16" carriage bolts, raise and support collector, and mount the hinges.
8. Lower the collector.
9. Attach the 2 - 1"x8"x16' with 16d nails into the ends of the vertical supports and 6d nails into the sides of the 16' horizontal supports, 6" on center.
10. Attach the roofing (adsorber) to the 2"x4"x16' horizontal supports with 6d nails on 12" spacings. Make sure that the corrugations run at right angles to the supports.
11. Attach 2"x2"s to the 2"x4"x16's by first drilling 1/8" pilot holes in the 2"x2"s (1' on center) and then nailing with 10d or 12d nails.
12. Prepare metal for priming by etching with a commercial etching solution, wiping clean and allowing to dry.
13. Paint the metal with a galvanized metal primer.
14. Paint metal and all other exposed surfaces with flat black paint. Make sure that the 1x2 battens are also painted black.
15. Attach the cover glazing material. The <u>inside</u> of the roll has a special coating to prevent degradation by ultraviolet light. so make sure that this surface is exposed to the outside air.

    Start from the bottom of the collector (that's the one with the 3 tee hinges) and unroll the glazing along the 2"x2" supports. Line the edges up so that they will overlap with the next line of glazing. Place the 1"x2" battens on top and drill 5/64" holes through the 1"x2" and glazing, 12" on center. Remove the 1"x2" and enlarge the hole in glazing by 1/16" (9/64). This allows clearance for expansion and contraction of the glazing due to heat.

Caulking is necessary only on the edges and lap joints, not at intermediate supports.

Use 1.5" #6 screws, 12" on center.

When installing 1"x2" battens, leave a 1.5" gap at each end of collector for the vertical batten.

Lumber for Collector

14 - 2"x4"x16'
6 - Sheets 1/2" 4'x8' C-D Exterior plywood
14 - 2"x2"x16' (or equivalent)
2 - 1"x8"x16'
5 - 2"x4"x12'
14 - 1"x2"x16' (or equivalent
2 - 1"x2"x12' (or equivalent)

Absorber

8 - Sheets 26"x12' 28 guage corrugated roofing

Lumber for Base

2 - 4"x6"x16'
3 - 2"x6"x8'
2 - 2"x4"x12'

Cover Glazing

1 - 50' roll (50" width) .040 "Sunlite" Premium II (Fiber Reinforced Plastic)

Nuts, Bolts

28 - 2 1/2 x 5/16" Carriage bolts/nuts
12 - 2"x 5/16" machine bolts/nuts
12 - 3 1/2"x 5/16" lag bolts

Nails

2 lb. - 10d or 12d common
4 lb. - 6d ring shank
2 lb. - 16d common

Screws

100 - 1.5" #6 wood screws

Pipe

2 - 4 1/2' Schedule 80 1" steel
2 - 4 1/2' Schedule 80 1.5" steel

Hardware

3 - 8" X-H.D. tee hinges
4 - 6" H.D. strap hinges
- 8"x12' # 1/4" Hardware screen

Paint

1/2 gallon galvanized metal primer - (Rustoleum #3202 or equivalent)
1 - gallon flat-black (Rustoleum #7776 or equivalent)
1 - gallon surface preparation (Rustoleum Surfa-Etch #108 or equivalent)

Caulk

1 - quart silicone caulking

MATERIALS FOR PLENUM

1 - 2"x6"x16'
6 - 2"x6"x6' blocks
1 - 2"x4"x12'
1.5 - sheets 4'x8'x1/2" C-D Exterior Plywood
2 - 1"x2"x8'

8 - #10 1 1/2" wood screws
4 - 1/4"x2" bolts w/nuts
4 - 1"x3" mending plates
8 - #8 1" wood screws
1 lb. 8d Common nails

MATERIALS FOR MIXING BOX WITH SINGLE DUCT

Lumber

4 - 4'x2"x2" Common
10 - 3'x2"x2" Common
2 - 1/2"x4'x8' C-D Ext. Plywood
1 - 3/4"x2'x3' C-D Ext. Plywood
2 - 1"x2"x4' Common
2 - 1"x3"x4' Common

Hardware

2 - 4" Tee hinges (or equivalent)
- 6d nails
- 8d nails

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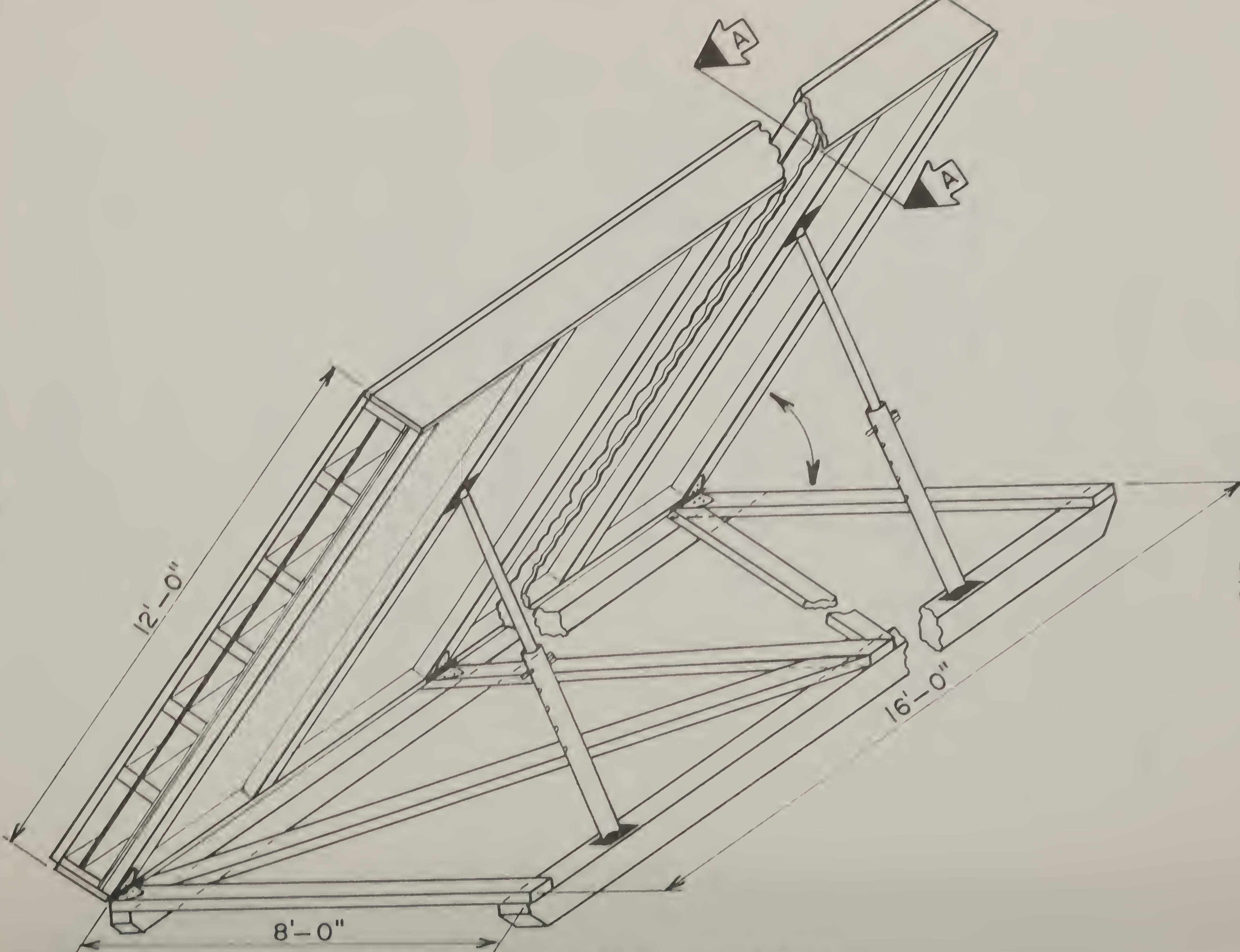
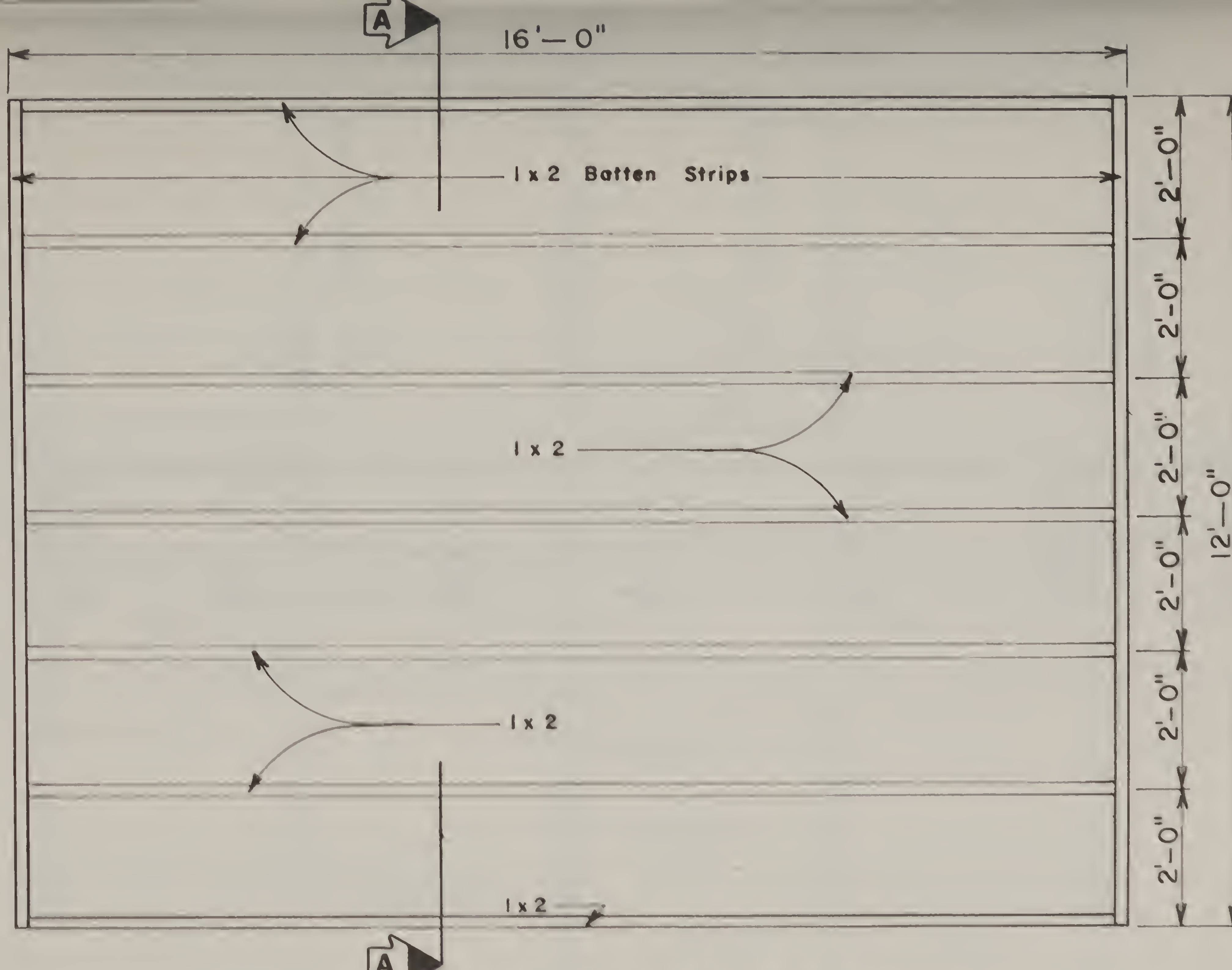
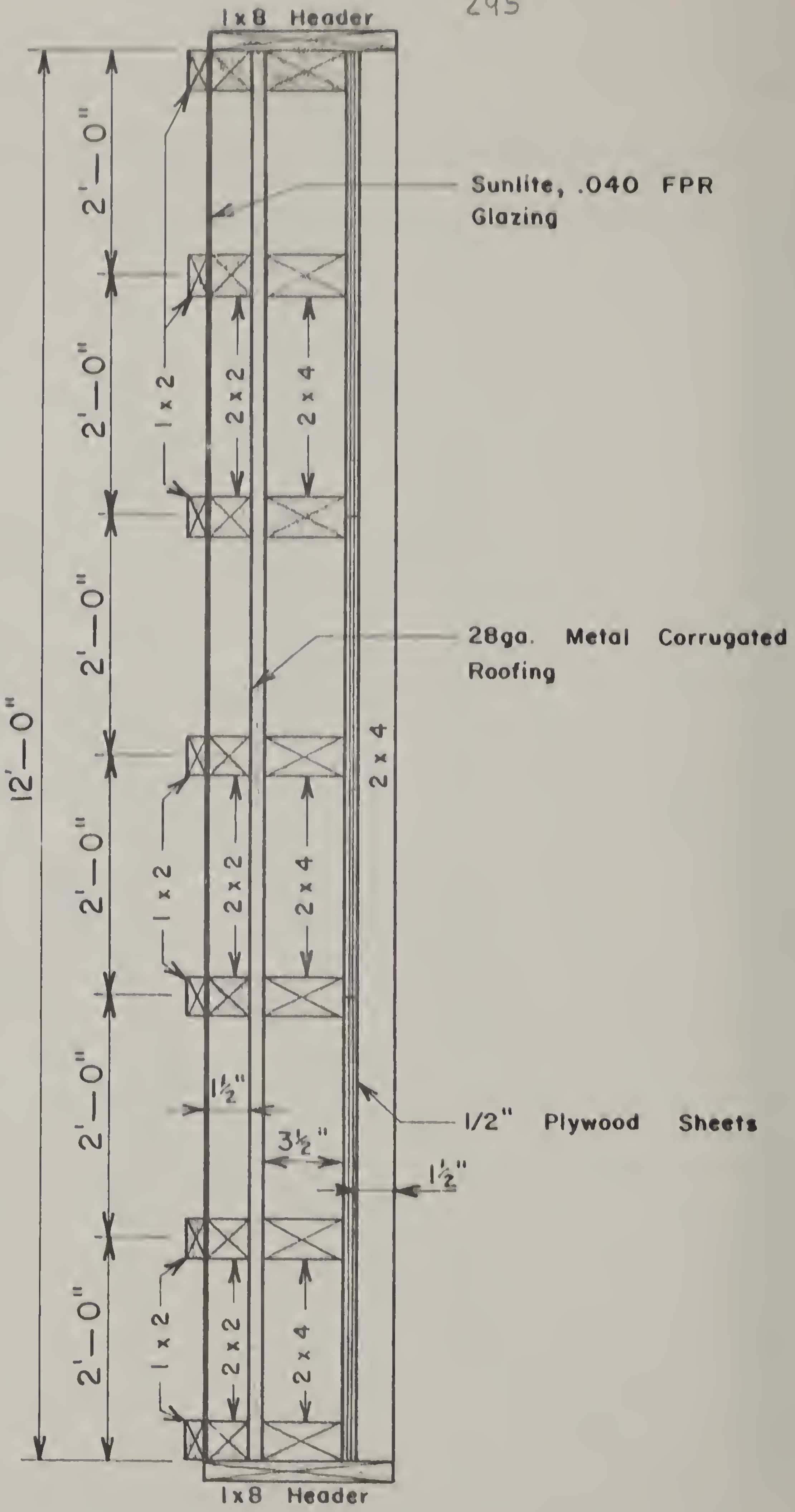


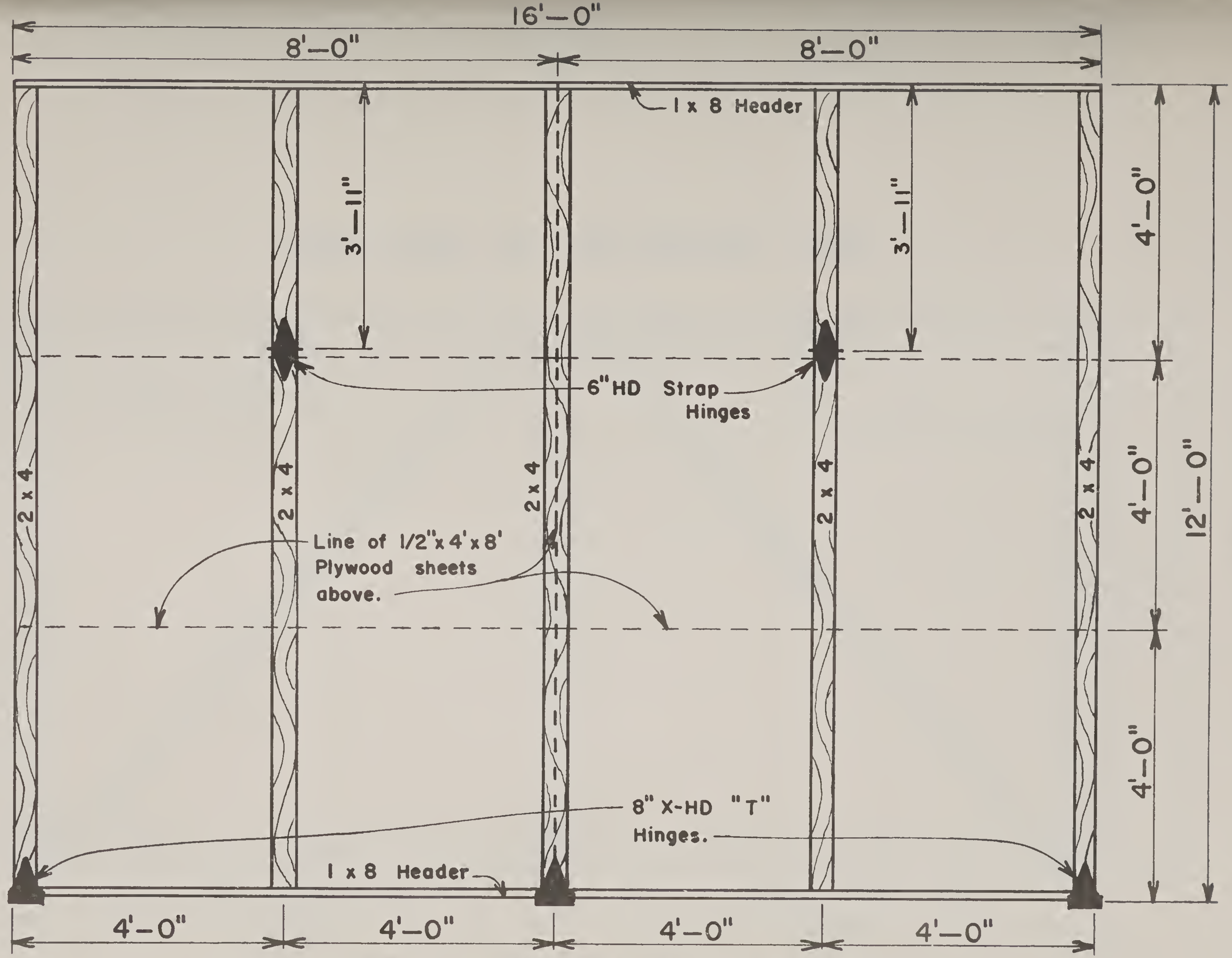
PORTABLE SOLAR COLLECTOR



FRONT VIEW OF COLLECTOR



COLLECTOR'S SECTION A—A



REAR VIEW & FRAMING OF COLLECTOR

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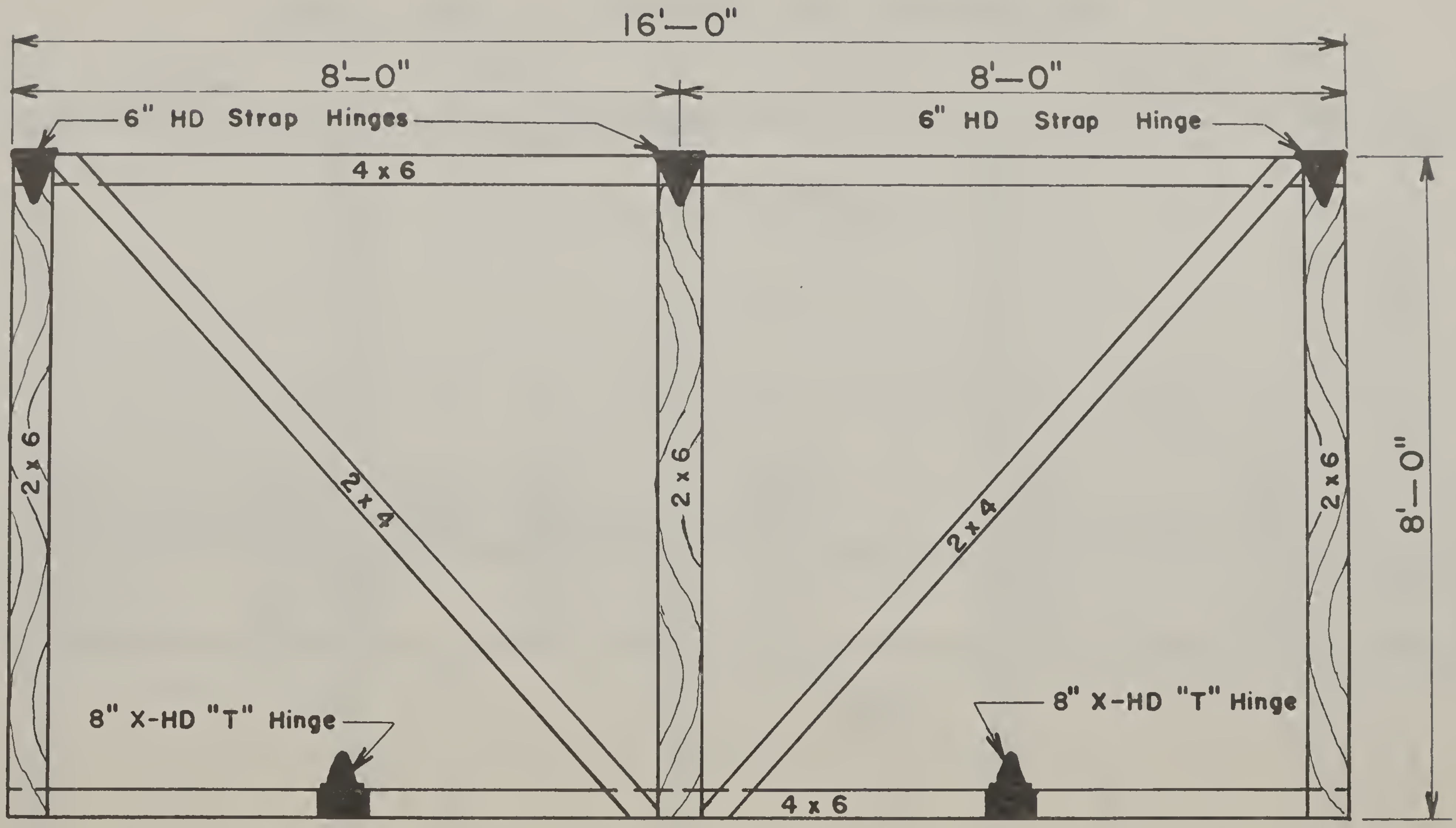

PLAN VIEW OF COLLECTOR'S SKID

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Final Report

ON-FARM SOLAR DRYING of CROPS in MICHIGAN

Demonstration Project
March, 1981 through December, 1982

Sponored by:

Department of Agricultural Engineering and
Cooperative Extension Service
Michigan State University
East Lansing, MI

In Cooperation with:

SEA-Extension
U. S. Department of Agriculture

and

U. S. Department of Energy

Personnel:

Ron Melvin, Graduate Assistant
Roger C. Brook, Extension Agricultural Engineer
Howard L. Person, Extension Agricultural Engineer

February, 1983

ON-FARM SOLAR DRYING of CROPS in MICHIGAN

The Department of Agricultural Engineering and the Cooperative Extension Service at Michigan State University began an agreement in early 1981 with USDA/SEA-Extension to demonstrate the use of solar energy for crop drying in Michigan. Pass through funds from the US Department of Energy were made available to select and monitor cooperating farms utilizing solar energy for crop drying. The objectives of the project were:

A. To demonstrate the technical aspect of utilizing solar energy facilities for the on-farm drying of agricultural crops and for supplying supplemental heat for related on-farm enterprises at various locations in Michigan.

B. To monitor solar radiation, ambient temperature, and ambient humidity for various locations in Michigan, and solar collector performance parameters for different types of solar collection equipment.

C. To estimate the economic feasibility of different types of solar collection equipment for agricultural uses at various locations in Michigan.

D. To arrange tours of the solar facilities for agricultural producers in Michigan and to publish the results of the monitoring activities and economic feasibility analysis for use by agricultural producers in Michigan.

Project Overview

One of the unique aspects of Michigan agriculture is the diversity of agricultural commodities produced in the state. As such, it was felt that the demonstration sites selected for participation in the project should include a diversity of agricultural commodities. Previous research in Michigan indicated that solar energy facilities used solely for crop drying may not be economically feasible, unless alternative uses of the equipment can be identified. Therefore, cooperating farm facilities were sought which included solar supplemented crop drying along with solar supplemented heating for swine farrowing/nursery units, dairy calf housing units and space heating applications. A total of nine cooperating sites were selected with the geographical distribution indicated in Figure 1. Of these nine sites, four sites (Cleveland, Rifenburg, Stountenberg and Kalamazoo Nature Center) never completed construction of their solar facilities. These four sites are not included in the individual site reports. Solar collector performance data and preliminary economic feasibility information is included for the remaining five solar facility sites selected for participation in the project.

FIG. 1: GEOGRAPHICAL DISTRIBUTION OF POTENTIAL SOLAR ENERGY DEMONSTRATION SITES IN MICHIGAN.

Collector Design

Several different solar collector facility designs were involved in the monitoring phase of the project. The sites and their solar collector characteristics are summarized in Table 1.

TABLE 1
Solar Collector Types and Sizes

Site Name	Collector Type	Area (ft)	Glazing	Orientation
Bivens	Wrap around on a storage bin	1206	Corrug. Filon	Variable at 90 degrees
Gidloff	Solar attic on dairy calf housing	686	Clear acrylic	South at 60 degrees
Henderson	Portable stand alone Illinois plan	288	Corrug. FRP	South at 60 degrees
Kempton	Solar attic on swine farrowing	2112	Filon	South at 18.4 degrees
Kendle	Inflatable plastic	192	Clear plastic	South at 60 degrees

Monitoring and Instrumentation

The economic feasibility of any solar energy facility is dependent on the amount of incident solar radiation and the efficiency characteristics of that facility. The lakes surrounding Michigan contribute to more cloudy weather and reduced solar radiation than at locations in other states of similar latitude. Unfortunately, solar radiation information has not been readily available for locations in Michigan other than East Lansing and Sault St. Marie. Therefore, we decided to not only determine the performance characteristics of each facility, but to also collect hourly solar radiation and ambient temperature data for the various locations in Michigan involved in the project.

Each of the five sites with completed solar facilities was equipped with a CR-21 data acquisition unit manufactured by Campbell Scientific Inc. Each CR-21 was equipped with sensors to monitor solar radiation (Li-Cor silicon pyranometer), ambient temperature and relative humidity (thermistor and styrene copolymer, respectively) and air temperatures into and out of the solar collector. The pyranometer was located on the collector surface. The ambient temperature and relative humidity sensor was placed in a shelter to minimize radiation effects. The data was recorded hourly on magnetic tape cassettes. These cassettes were collected monthly and transferred to campus for further analysis. Data

for each site was to be collected continuously from October 1, 1981 through the end of November, 1983. Due to the early termination of all the state projects, the hourly solar radiation data was collected from October 1, 1981 through May 31, 1982. Each solar facility was analyzed in detail during the fall of 1982 to determine its collector performance characteristics. During this time, the airflow through each collector was measured using an Alnor velometer. The collector performance characteristics thus determined would have allowed an extended analysis of the different types of collectors at the different geographic locations in Michigan had the project been funded for its third year.

The average monthly solar radiation for each of the five sites monitored during the fall of 1981 is summarized in Table 2. The average monthly temperature for each of the five sites monitored during the fall of 1981 is summarized in Table 3.

TABLE 2
Monthly Solar Radiation for Fall, 1981 in BTU/sq ft-day
Average value and (standard deviation) on inclined surface

Site Name	October	November	December
Bivens	609	661	520
	(416)	(723)	(579)
Gidloff	1010	--	1287
	(829)	--	(579)
Henderson	894	768	570
	(631)	(197)	(554)
Kempton	(a)	--	--
	--	--	--
Kendle	1170	946	783
	(760)	(735)	(616)

(a) No solar radiation information is available due to a malfunction of the pyranometer.

TABLE 3
Monthly Temperatures for Fall, 1981 in degrees F
Average values and (standard deviation)

Site Name	October	November	December
Bivens	44 (5.8)	41 (8.4)	39 (5.0)
Gidloff	50 (3.1)	-- --	41 (7.3)
Henderson	46 (7.1)	54 (7.7)	38 (5.2)
Kempton	40 (7.1)	35 (7.7)	37 (5.2)
Kendle	49 (6.5)	40 (9.1)	38 (6.5)

Collector Performance Characteristics

The calculated performance characteristics for each of the five sites monitored are summarized in Table 4. These characteristics were estimated using data taken at each site during the fall of 1982.

TABLE 4
Solar Collector Performance Characteristics

Site Name	Measurement Date	Airflow (cfm)	Incident Solar (btu/hr)	Solar Gain (btu/hr)	Average Efficiency (percent)
Bivens	Sept. 20, 1982	11,927	400,973	191,264	47.7
Gidloff	Oct. 31, 1982	15,763	206,013	115,779	56.2
Henderson	Dec. 16, 1982	3,644	49,924	11,836	23.7
Kempton	Sept. 24, 1982	13,032	486,705	138,711	28.5
Kendle	(a)	--	--	--	--

(a) Due to problems experienced with the solar collector during the fall of 1982, data for a detailed performance analysis of this solar collector system was not collected.

Preliminary Economic Feasibility

A program developed for analyzing the economics of solar hot-water heating has been modified for use in determining break-even investments for solar collector units for crop drying. The program is written for the TI-59 programmable calculator manufactured by Texas Instruments Inc. The solar collector characteristics presented in Tables 1 and 4 were used for each site. The preliminary economic feasibility analysis (break-even) results are presented in Table 5. These results assume that for crop drying the solar collector units will be used for a total of 30 days during the fall. The range of break-even costs per square foot result from the maxima and the minima of the observed solar radiation values as presented in Table 2. The following factors and assumptions were used in calculating the break-even costs for the solar facilities monitored:

Annual interest rate (applies to the total cost)	10 %
Term of the loan	5 years
General inflation rate	10 %/yr
Fuel cost escalation rate	10 %/yr
Discount rate (after tax return on best alternative investment)	12 %/yr
Cost of conventional fuel (LP gas at $0.80/gal.)	$8.65 per Million BTU
Efficiency of conventional combustion equipment	75 %
Federal income tax bracket	30 %
Insurance and Maintenance (fraction of investment)	1 %
Period of economic analysis	10 years

When considering solar heat versus other heat sources, the user must consider not only the break-even cost, but the potential savings in capital equipment if no other heat producing device is included in the system, the potential return for space heating uses, and any applicable tax credits. The analysis presented above does not consider the benefit of using the solar collector to supplement space heating needs on the farm.

TABLE 5
Preliminary Economic Analysis

Site Name	Break-Even ($/sq ft)	Construction ($)	Cost ($/sq ft)	Construction Year
Bivens	0.74 - 0.94	1100.00	0.91	1980
Gidloff	1.69 - 2.15	4835.00	7.05	1981
Henderson	0.40 - 0.63	600.00	2.08	1979
Kempton (a)	0.47 - 0.72	1675.00	0.79	1980
Kendle		1900.00	9.90	1980

(a) Economic analysis performed using solar radiation data of 550 - 850 btu/sq ft-day.
(b) Economic analysis not due to lack of performance data for fall, 1982.

Conclusions

Solar energy for crop drying is weather dependent and my be least successful during the years when it is needed most. During years when the crops mature late or when field drying conditions are poor, solar radiation levels are usually low. In many areas of the state of Michigan back-up heat systems may be desirable. This will limit the attractiveness of solar energy usage because the cost of collecting solar energy can be offset only by savings in fuel costs.

The economic feasibility of solar crop drying systems is largely related to savings in fuel versus the investment cost for the solar collectors. Fuel costs especially are likely to continue to rise in the coming years, and this may alter the disadvantages of solar energy use for crop drying in Michigan. The cost of solar collectors and the small amount of energy collected during the crop drying season are limiting enough that a producer would not want to replace usable conventional equipment. It is not yet clear if a new facility can justify the expense of the solar collectors. It appears that a natural air drying system may be equally workable in Michigan without the additional expense of the solar collectors.

Investigations into the use of solar energy for crop drying in Michigan have resulted in the following conclusions:

A. Solar drying has a better chance for success when it is started later in the fall. This is basically due to the lower ambient temperatures as the fall season progresses. Mold growth rate will double with each 10 to 15 degree increase in temperature.

B. The maximum recommended moisture content for grain in a solar drying system is approximately 22%, using an airflow rate of 2 cfm per bushel of grain to be dried.

C. Solar collectors should be sized according to the amount of grain to be dried. A range of 0.1 - 0.3 square feet of collector per bushel of grain is recommended.

D. The use of solar collectors will reduce the necessary drying time and therefore the period of fan operation. The quality of the crop dried in a solar drying system is generally similar to the quality of the crop dried using a natural-air drying system.

E. The use of heat energy supplied by the solar collectors will result in frequent over-drying of the bottom layers of grain in the drying bin. The over-drying can be alleviated to some extent through the use of stirring devices, but these represent an additional expense.

F. The energy requirements of the bin drying process are reduced when using a solar collection system, but the energy savings will generally not be sufficient to justify the expense of the solar collectors.

Summary

The solar crop drying demonstration project described above was initially funded for the period March, 1981 through September, 1983. During the spring of 1981, several of the cooperating facilities were identified and the monitoring equipment was purchased. The monitoring equipment was installed in five of the cooperating sites during the summer of 1981 and data collection began in October of that year. It was our intention to collect this data continuously through the end of the project, and to likely continue through the fall of 1983. The data collected on this basis was not sufficient for a detailed performance analysis of these units, but would have allowed us to establish a better understanding of the distribution solar radiation within the state of Michigan. We then planned to perform detailed performance analysis on each of the solar facilities during the fall of 1982 and the winter of 1983.

Unfortunately, the funding for this project was terminated effective September, 1982. Since we needed some data collection and analysis time during the fall of 1982, the collection of ambient solar and temperature data was halted in late spring, 1982. Personnel assigned to the project were reassigned for the summer months to other projects. This left enough money to accomplish an abbreviated form of the planned analysis of performance characteristics. The performance characteristics determined were used to begin the economic feasibility analysis reported above. The economic feasibility analysis will continue through the winter of 1983 under funding from the Cooperative Extension Service, Michigan State University.

Three Cooperative Extension Service meetings are scheduled are scheduled during the winter of 1983 which will discuss the current results from this project with agricultural producers in the state of Michigan.

SOLAR ENERGY for FARMSTEAD HEAT APPLICATIONS
The Lavern Bivens Farm

Lavern Bivens, a builder/farmer in southwestern Michigan, initially constructed during the summer of 1979 an air-type solar collection system which consists of a solar attic on top of a warehouse/office building. The solar heated air from the attic is delivered to two drying bins through a system of ducts, or it may be delivered directly to the warehouse/office space through a damper arrangement. He later constructed a wrap-around solar collector on a corn drying bin during the fall of 1980. Mr. Bivens agreed to cooperate with the Agricultural Engineering Department and the Cooperative Extension Service of Michigan State University in evaluating the performance characteristics and economic feasibility of each of the wrap-around solar collector system for drying corn.

The Farm

Lavern Biven's farm is located beside M-66 about 8 miles south of Nashville in Barry County, Michigan. The farm contains approximately 1100 acres out of which 800 acres are used for growing corn, and 150 acres each for growing wheat and soybeans.

There are four bins on the farm which are arranged as shown in Figure 1, with three of these bins set up for solar drying of any of the harvested crops. Bins 3 and 4 are connected to the roof solar collector which is about 30 feet away to the north of the bins. Bin 1 has the wrap-around solar collector with the center of the collector area facing south. Each of the four bins has a diameter of 36 feet, an eave height of 18 feet and is capable of holding nearly 15,000 bushels of grain. Each bin is equipped with a 20 HP centrifugal fan and a 20 kilowatt heater which is controlled by a humidistat. The fans each are capable of delivering 19,300 cfm of air at zero static pressure.

The Demonstration Goals

1. To measure the amount of incident solar radiation that could be collected at the farm over a total drying season.

2. To estimate the performance characteristics of the wrap-around solar collector system.

3. To estimate the economic feasibility of the wrap-around solar collector system under Michigan conditions.

The Collector System

The solar collector system consists of a wrap-around collector attached to Bin 1 as illustrated in Figure 1. This is a covered plate collector constructed from a transparent fiberglass material known as Filon, which is wrapped around the southern two-thirds of the bin. The blackened bin

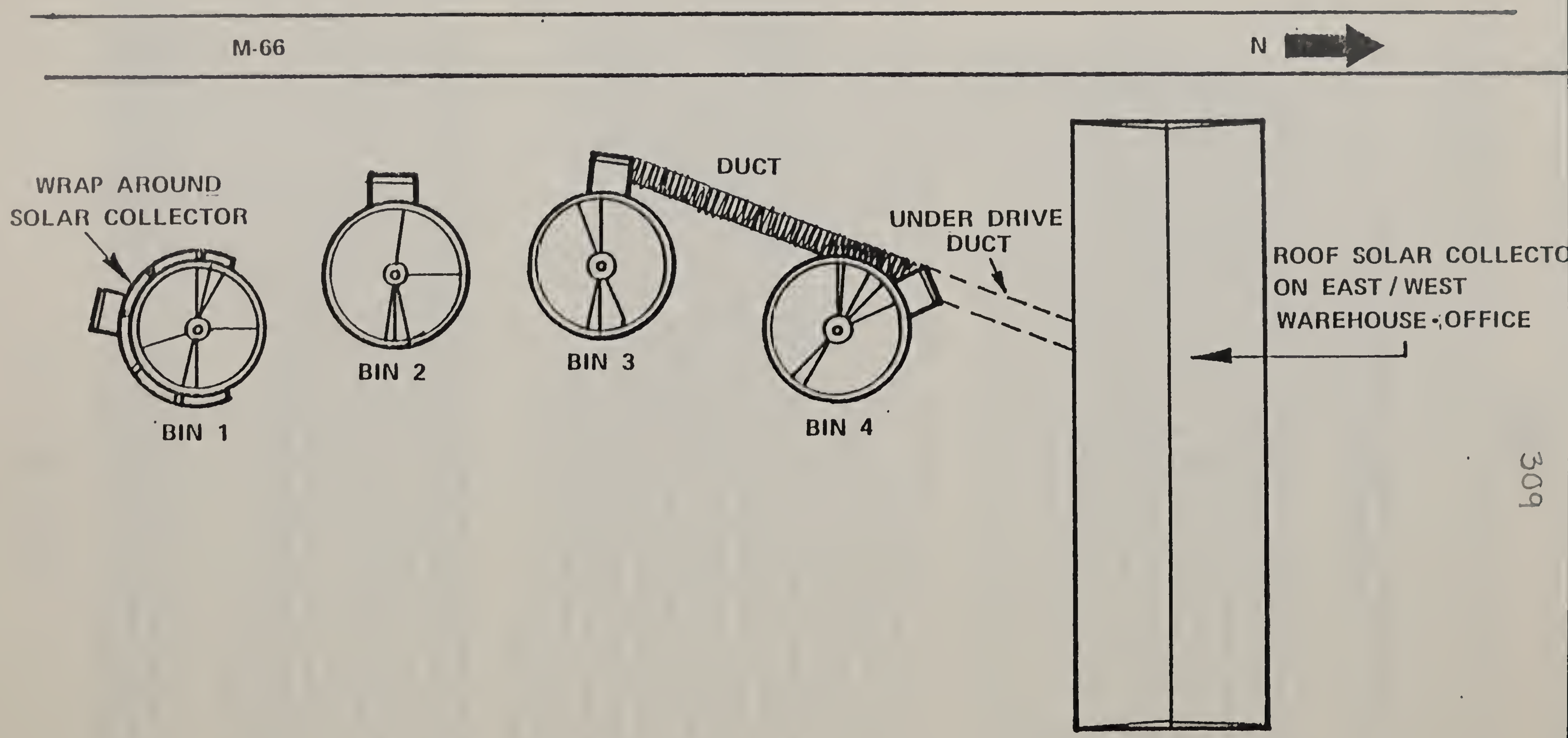

FIG. 1: SCHEMATIC LAYOUT OF THE SOLAR FACILITY AT THE BIVENS FARM.

wall serves as the absorber of the trapped solar energy. The collector is 16 feet high and completely covers the drying fan on the south side of the bin. The supports for the cover material run vertical to allow trapped air to easily exit upwards during the summer months.

The air inlet to the collector is a 9 inch air gap between the top of the collector cover material and the bin eave. The air is heated in the enclosed space between the collector and bin by the trapped radiant energy. The solar heated air is then drawn into the drying bin through an 18 inch duct around the bottom of the bin. A cut-away view of the collector system illustrating the airflow pattern is in Figure 2.

The Instrumentation

The solar site was equipped with a CR-21 data logger. The instrument recorded hourly averages of the parameters listed below:

Solar Radiation (incident on the collector surface)
Ambient Temperature
Ambient Relative Humidity
Collector Inlet Temperature
Collector Outlet Temperature
Drying Bin Inlet Temperature

The airflow supplied for grain drying was assumed to be constant during the drying season, and was measured using an Alnor Velometer air velocity meter. The parameters listed above were recorded for the time period October 1, 1981 through June 15, 1982. The parameters were then recorded for another period during the fall of 1982 when detailed analysis of the solar collector performance characteristics was done.

The Solar System Performance

The performance characteristics of the solar collector when used for drying grain were estimated using data collected during the fall of 1982. The following information was recorded or calculated for the wrap-around solar collector system:

Drying airflow	11,927 cfm
Incident solar radiation (on collector surface)	400,973 btu/hr
Total solar gain	191,264 btu/hr
Average efficiency	47.7 percent

Based on this data, the break-even investment for this solar energy facility is in the range of $0.74 - 0.94 per square foot of collector. When considering solar heat versus other heat sources for crop drying, this cost must be considered in addition to the potential savings in capital equipment if no other heat producing device is included in the system, the potential return for additional space heating uses, and any applicable tax credits (state and federal).

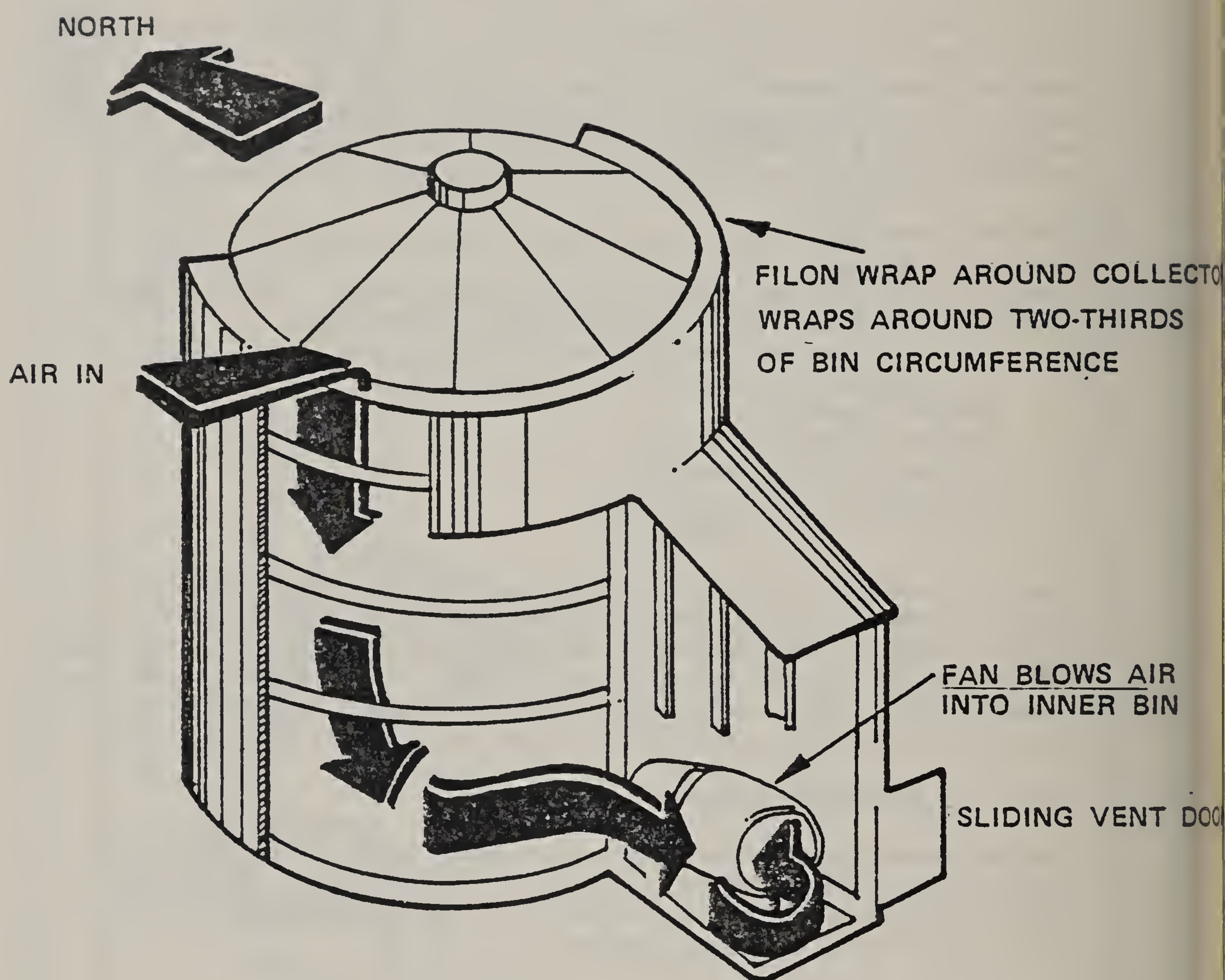

FIG. 2: CUTAWAY VIEW OF THE WRAP AROUND SOLAR COLLECTOR ON THE BIVENS FARM.

Commentary

Mr. Bivens is, in general, happy with his collector. He builds and sells solar collectors of this type, hence his views may be somewhat biased. However, he would not have gone into building collectors unless he believed in them. He wants to help free others from the increasing energy costs and feels that solar collectors are one way to fulfill this goal. The wrap-around collector of this type is probably the best type of solar collector for grain drying as any included in the MSU solar crop drying monitoring project. However, the question still remains as to the necessity of using a solar collector at all in that type of drying system. Alternatively, a natural-air drying system would probably be equally effective, and cost less.

SOLAR ENERGY for FARMSTEAD HEAT APPLICATIONS
The Bert Gidloff Farm

Bert Gidloff, a dairy farmer in northern Michigan (upper peninsula), constructed in 1979 a solar collection system which consists of a solar attic on top of a dairy calf housing unit. Mr. GIdloff agreed to cooperate with the Agricultural Engineering Department and the Cooperative Extension Service of Michigan in evaluating the performance characteristics an economic feasibility of the solar system.

The Farm

Bert Gidloff's farm is located on county road G-12 about 4-1/2 miles east of Stephenson in Menominee County, Michigan. Corn and oats are grown on approximately 200 acres of the 480 acre farm. The remainder of the acreage is used for haylage and corn silage. The farm buildings consist of calf housing, milking cow housing and silos. The location of each building is illustrated in Figure 1.

The calf housing unit is a regular pole-building. A steel ceiling on the inside has about 10 inches of blown insulation on top. The main frame of the building consists of the exterior and interior walls with a 6 inch fiberglass batt between. The exterior wall is steel and the top half of the interior wall is also steel. The bottom half of the interior wall is plywood. There are three 18 inch diameter exhaust fans in the calf barn, two of which are regular fans with one thermostat each, and the third is a variable-speed fan. There is no heat storage facility under or around the building.

A corn drying bin could be located on the east end of the building, but has not been constructed.

The Demonstration Goals

1. To measure the amount of incident solar radiation that could be collected at the farm over a total drying and heating season.

2. To estimate the performance characteristics of the solar attic collector system.

3. To estimate the economic feasibility of the solar attic collector system under Michigan conditions.

The Collector System

The solar collector consists of the east-west roof facing south. This roof has a 60 degree slope and is 80 feet long. The cover material for the south-facing half of the roof is clear acrylic. The absorber is insulation board covered with a black paper-like material. The northern half of the solar attic consists of white steed roofing and siding. There is no vertical divider at the center of the attic.

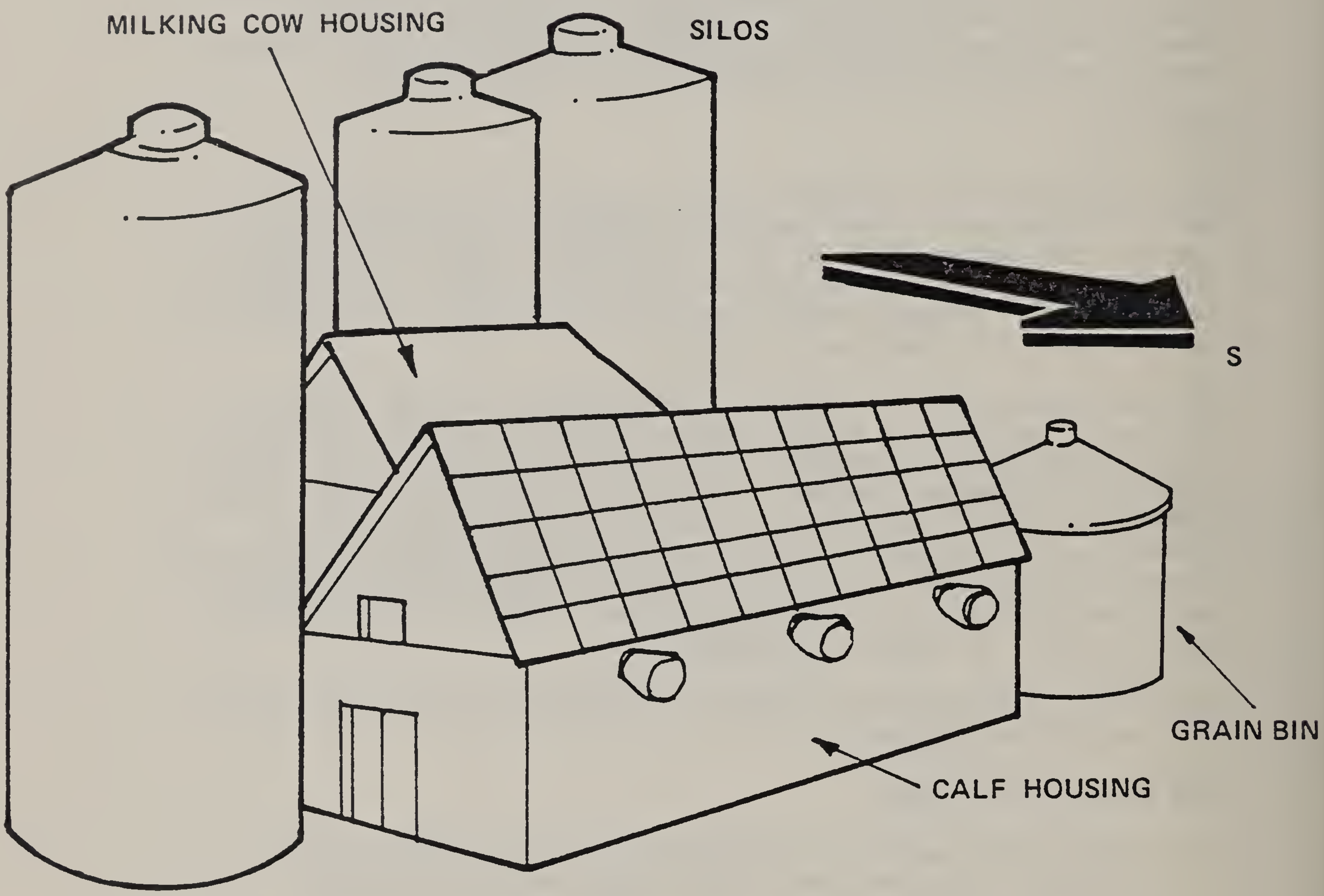

FIG. 1: SCHEMATIC LAYOUT OF THE BUILDINGS ON THE GIDLOF FARM.

During the winter season, entry of air into the solar attic is through the ridge vent and/or the eave vents on the north side of the attic, as illustrated in Figure 2. The air flows over the absorber plate from the top of the south roof and exits into a collection duct which runs along the full length of the building at the bottom of the south facing roof. Two transfer ducts connect the collection duct to the distribution duct in the steel ceiling of the building. All ducts are insulated. There are two 12 inch fans in the attic that are used for moving solar-heated air into the distribution duct. The solar-heated air enters the calf housing through adjustable shutters located at the bottom of the distribution duct.

The Instrumentation

The solar site was equipped with a CR-21 data logger. The instrument recorded hourly averages of the parameters listed below:

- Solar Radiation (incident on the collector surface)
- Ambient Temperature
- Ambient Relative Humidity
- Collector Inlet Temperature
- Collector Outlet Temperature
- Calf Housing Temperature

The airflow supplied for supplemental heating varies depending on the ventilation requirements, and was measured using an Alnor Velometer air velocity meter. The parameters listed above were recorded for the time period October 1, 1981 through December 15, 1982. The parameters were then recorded for another period during the fall of 1982 were used for a detailed analysis of the solar collector performance characteristics.

The Solar System Performance

The performance characteristics of the solar collector when used for drying grain were estimated using data collected during the fall of 1982. The following information was recorded or calculated for the solar attic collector system:

Drying airflow	15,763 cfm
Incident solar radiation (on collector surface)	206,013 btu/hr
Total solar gain	115,779 btu/hr
Average efficiency	56.2 percent

Based on this data, the break-even investment for this solar energy facility is in the range of $1.69 - 2.15 per square foot of collector. When considering solar heat versus other heat sources for crop drying, this cost must be considered in addition to the potential savings in capital equipment if no other heat producing device is included in the system, the potential return for additional space heating uses, and any applicable tax credits (state and federal).

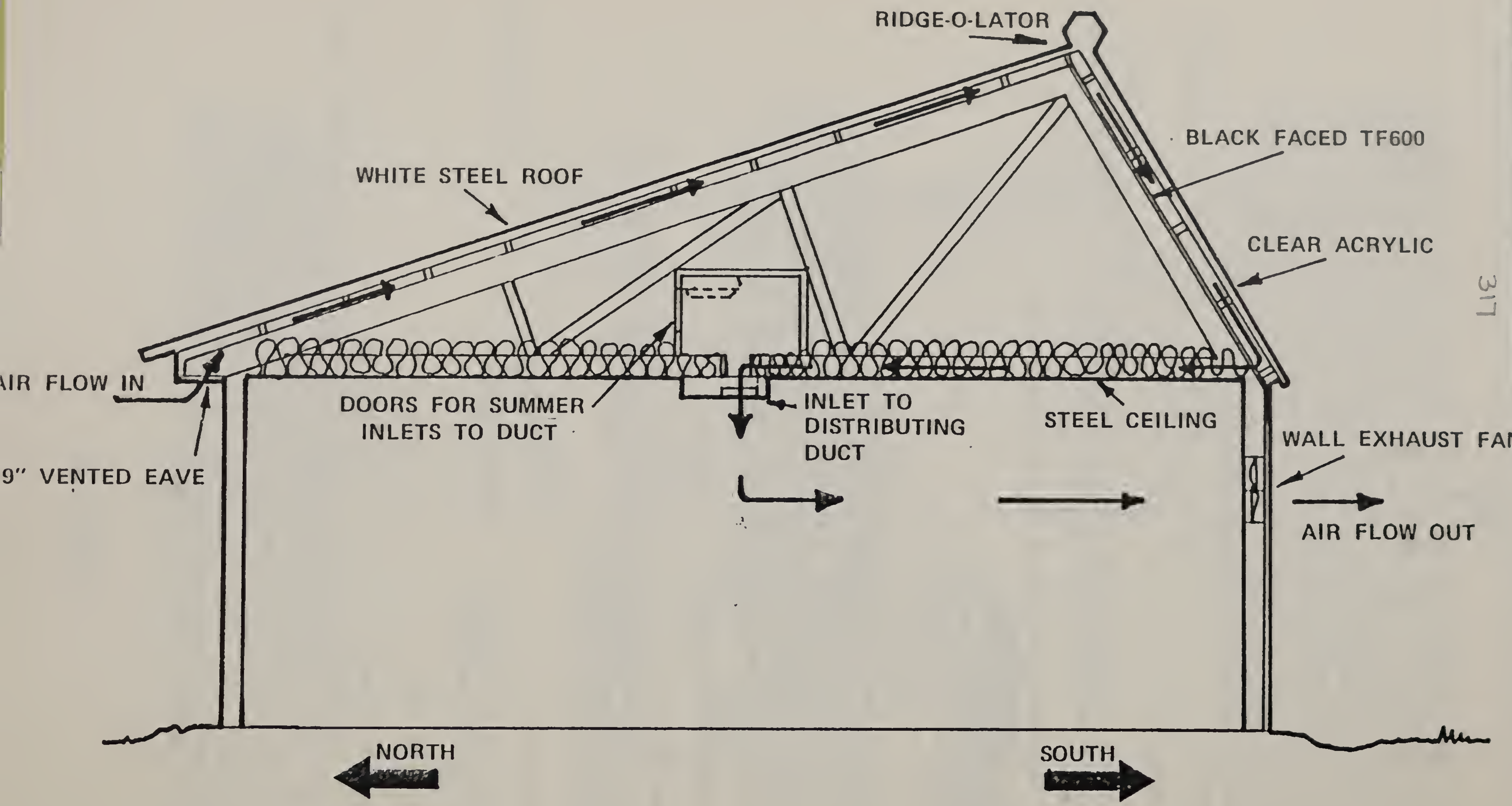

FIG. 2: SECTION OF THE CALF HOUSING BUILDING ON THE GIDLOF FARM, INDICATING AIR FLOW.

Commentary

Although the collector could not be used for grain drying, Mr. Gidloff has indicated to us that the collector works very well all winter long for heating the dairy calf housing barn. He has said that on a clear day in the winter with temperatures as low as -10 degrees F, that the inside temperature remains around 65 degrees F. This, of course, includes the heat generated by the calves in the barn. He has had no real problems with the set-up and would recommend the solar collector system to anyone. This collector is well suited to heating a livestock housing unit. It would not likely perform as well when used for grain drying, partly due to the increased airflow through the attic collector, and partly due to the losses through the required run of duct to reach a grain bin.

SOLAR ENERGY for FARMSTEAD HEAT APPLICATIONS
The William Henderson Farm

William Henderson, a cash crop farmer in southwest Michigan, constructed a portable solar collector (plan originally developed at the University of Illinois) in the summer of 1979. The solar collector is used to supply heat for drying corn without any form of supplemental heat. Mr. Henderson agreed to cooperate with the Agricultural Engineering Department and the Cooperative Extension Service of Michigan State University in evaluating the performance characteristics and economic feasibility of this solar system for drying corn.

The Farm

William Henderson's farm is located at 52383 Hutchinson Road, Three Rivers in St. Joseph, Michigan. The farm contains approximately 96 acres available for cropping with 56 and 40 acres used for growing corn and soybeans, respectively.

The drying bin on the farm has a diameter of 24 feet, an eave height of 12 feet and is capable of holding 6000 bushels of grain. A 24 inch diameter axial fan with a 5 HP motor is mounted on the bin and is capable of delivering 14,000 cfm of air at zero static pressure.

The Demonstration Goals

1. To measure the amount of incident solar radiation that could be collected at the farm over a total drying season.

2. To estimate the performance characteristics of the portable solar collector system.

3. To estimate the economic feasibility of the portable solar collector system under Michigan conditions.

The Collector System

The inclined solar collector (63 degree tilt angle) is set up facing due south as illustrated in Figure 1. It is 24 feet long and 12 feet wide and is anchored securely to the ground by cables to guard against wind damage. The collector has a black painted plywood absorber plate and a corrugated reinforced fiberglass cover. The collector is supported on the north side by a black painted plywood duct.

The air inlet is 6 inches wide running the full length of the top of the collector and is covered with 1/4 inch hardware cloth. The entering cold air is heated in the enclosed space between the plywood absorber and the fiberglass cover as illustrated in Figure 2. The solar heated air exits from a continuous 6 inch slot running the full length of the bottom of the collector. The heated air is then drawn into the drying bin by the drying fan.

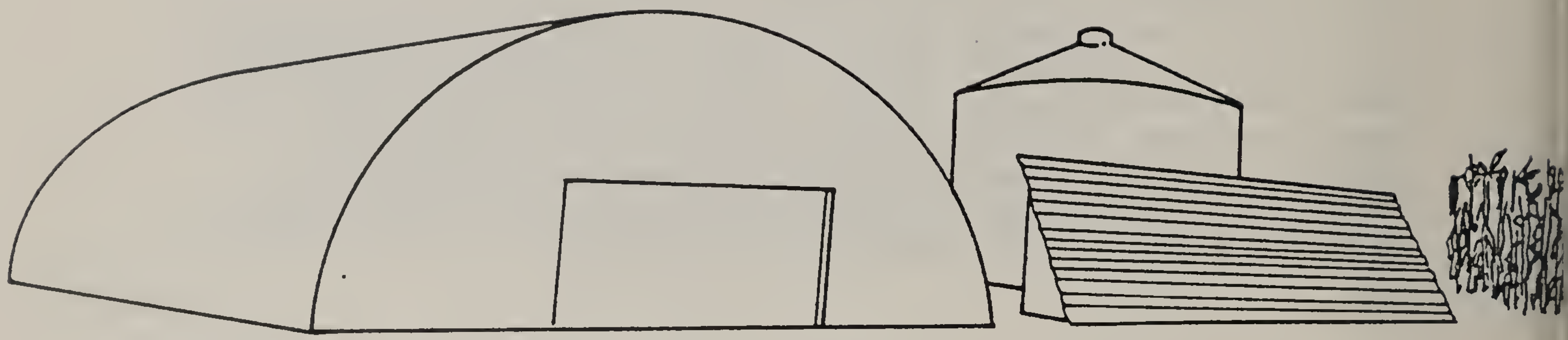

FIG. 1: SCHEMATIC LAYOUT OF THE BUILDINGS ON THE HENDERSON FARM

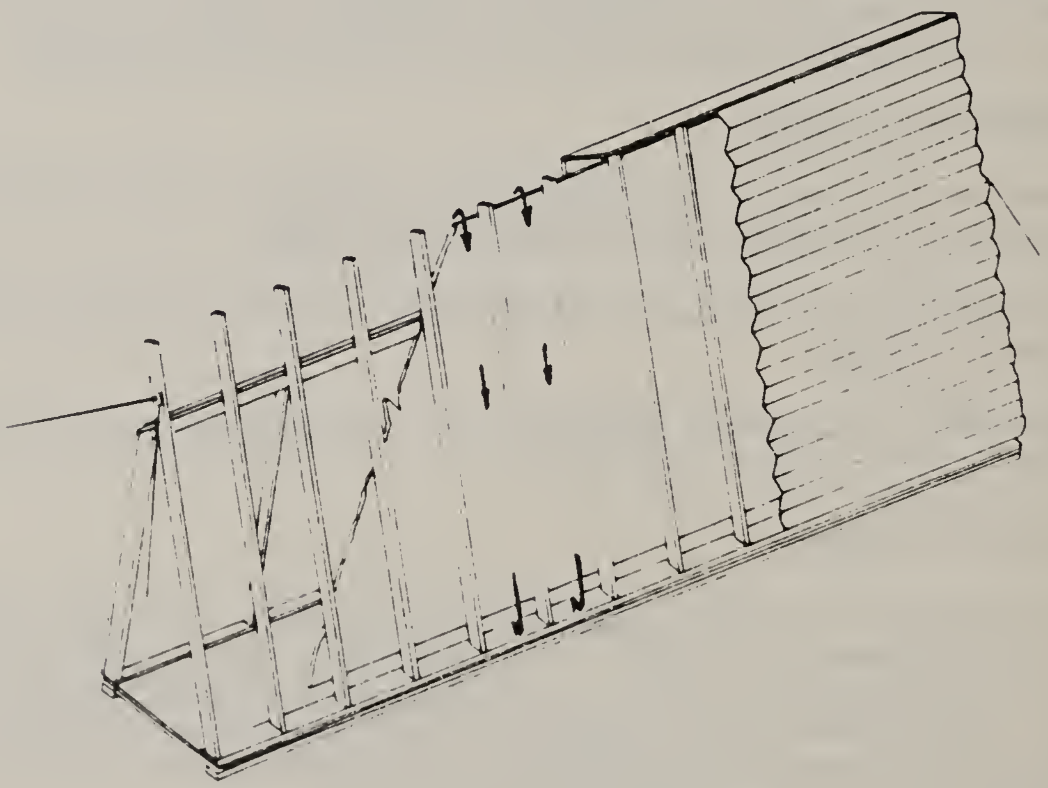

FIG. 2: CUTAWAY VIEW OF SOLAR COLLECTOR SHOWING AIR FLOW

The Instrumentation

The solar site was equipped with a CR-21 data logger. The instrument recorded hourly averages of the parameters listed below:

Solar Radiation (incident on the collector surface)
Ambient Temperature
Ambient Relative Humidity
Collector Inlet Temperature
Collector Outlet Temperature
Drying Bin Inlet Temperature

The airflow supplied for grain drying was assumed to be constant during the drying season, and was measured using an Alnor Velometer air velocity meter. The parameters listed above were recorded for the time period October 1, 1981 through June 15, 1982. The parameters were then recorded for another period during the fall of 1982 when detailed analysis of the solar collector performance characteristics was done.

The Solar System Performance

The performance characteristics of the solar collector when used for drying grain were estimated using data collected during the fall of 1982. The following information was recorded or calculated for the portable solar collector system:

Drying airflow	3.644 cfm
Incident solar radiation (on collector surface)	49,924 btu/hr
Total solar gain	11,836 btu/hr
Average efficiency	23.7 percent

Based on this data, the break-even investment for this solar energy facility is in the range of $0.40 - 0.63 per square foot of collector. When considering solar heat versus other heat sources for crop drying, this cost must be considered in addition to the potential savings in capital equipment if no other heat producing device is included in the system, the potential return for additional space heating uses, and any applicable tax credits (state and federal).

Commentary

Mr. Henderson indicated that he is very happy and satisfied with his solar collector. Whether drying corn or soybeans, he has found the heating to be sufficient to dry the grain to a marketable moisture content without experiencing any spoilage. He usually dries corn from 23% moisture to 14.5% moisture. The question still remains as to whether or not the heat source is necessary in this type of drying system.

SOLAR ENERGY for FARMSTEAD HEAT APPLICATIONS
The Arnie and Rick Kempton Farm

Arnie and Rick Kempton, cash crop and hog farmers in central Michigan, constructed in late 1980 a solar collection system which consists of a solar attic on top of an office/livestock building. The Kempton's have agreed to cooperate with the Agricultural Engineering Department and the Cooperative Extension Service of Michigan State University in evaluating the performance characteristics and economic feasibility of this solar system.

The Farm

The Kempton farm is located at 8128 5-mile Road, Mecosta in Mecosta COunty, Michigan. Corn is grown on approximately 250 acres of the 300-acre farm, while wheat is grown on the remaining 50 acres. The office/livestock building consists mainly of an office, 5 farrowing units on the north side of the building and 3 nursery units on the eat end of the building.

The harvested wheat is field dried, but the harvested corn is presently dried using LP gas. Of the three bins on the farm as illustrated in Figure 1, bin A is intended for solar drying because it is the closest to the solar attic. This batch drying bin has a diameter of 21 feet, an eave height of 18 feet and is capable of holding 6000 bushels of corn. A 24 inch axial fan with a 7-1/2 HP motor is mounted in this drying bin. This fan is capable of delivering 16,600 cfm of air at zero static pressure.

The office/livestock building is 48 feet wide by 88 feet long. The main frame of the building is constructed with steel wall which have 6 inches of batt insulation internally. Each of the livestock units is provided with an exhaust fan, resulting in a total of three 10 inch diameter fans in the nursery units and five 8 inch diameter fans in the farrowing units. There is no heat storage facility under or around the building.

The Demonstration Goals

1. To measure the amount of incident solar radiation that could be collected at the farm over a total drying and heating season.

2. To estimate the performance characteristics of the solar attic collector system.

3. To estimate the economic feasibility of the solar attic collector system under Michigan conditions.

The Collector System

The solar collector consists of the south facing east-west roof of the office/livestock building. The roof has a 4/12 slope with the south

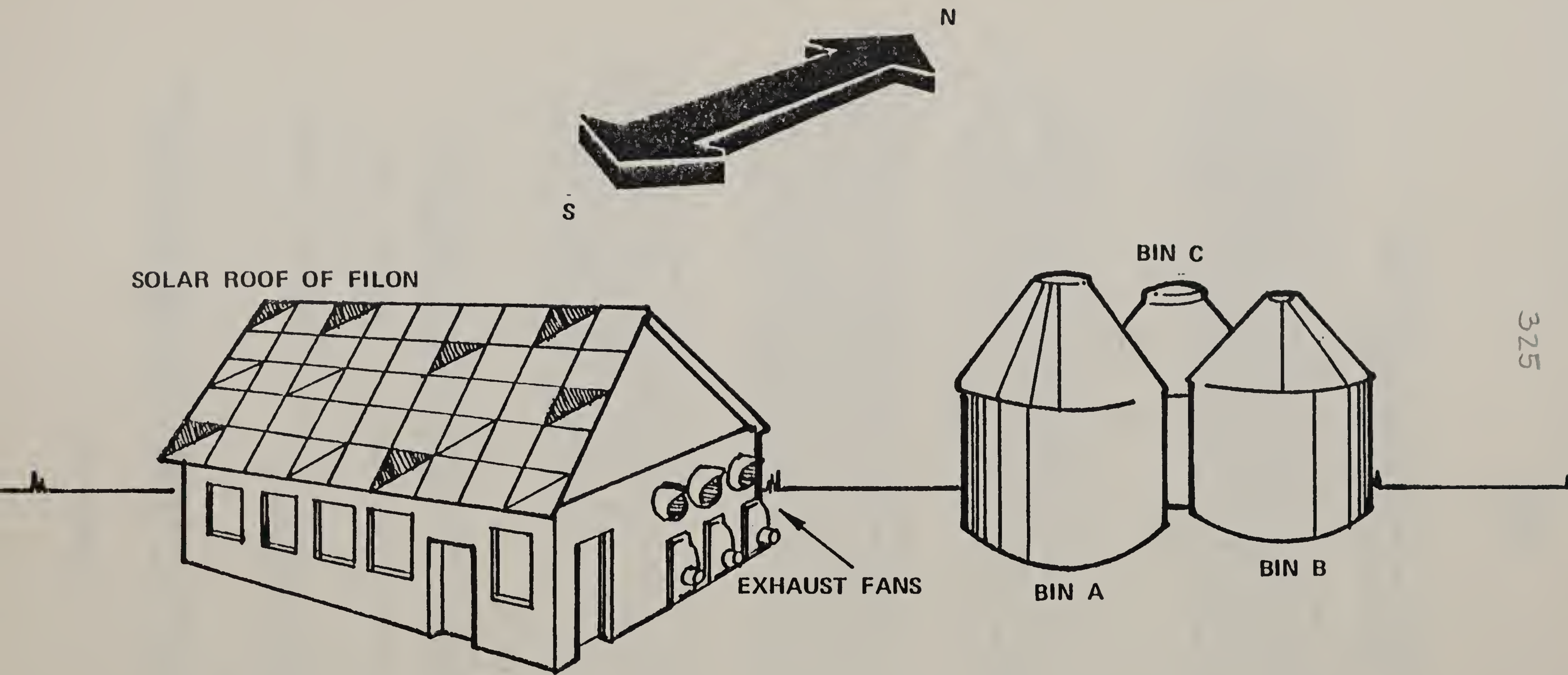

FIG. 1: ARRANGEMENT OF OFFICE/LIVESTOCK BUILDING AND DRYING BINS ON THE KEMPTON FARM.

face being covered with corrugated Filon and the north facing slope being covered with conventional metal roofing. The ceiling of the livestock area is 3/8 inch plywood which is insulated on top. There is a vertical plywood divider at the center of the attic for separating the northern and southern halves of the attic. The divider is painted black on the south side.

During the winter season, entry of air into the solar attic is through a sliding door at the west end of the attic, illustrated in Figure 2. cold air is drawn into the attic space and heated. The warmed air enters the interior of the building through five 8 x 24 inch shutters located in the ceiling along the south wall. The opening and closing of these shutters is manually controlled, depending on the temperatures in the attic and in the livestock housing units. The warm air that enters the building is moved through each livestock housing unit by the operation of the individual exhaust fan. The air is not recirculated, and the airflow rate fluctuates depending on ventilation requirements.

During the grain drying season, the solar attic is attached to the batch drying bin to provide supplemental heat. The intake of the drying fan is connected to two 12 inch insulated ducts which attach to the east end of the building. Cold air is drawn through the west end of the building, heat in the attic space, and then drawn into the intake of the drying fan.

The Instrumentation

The solar site was equipped with a CR-21 data logger. The instrument recorded hourly averages of the parameters listed below:

Solar Radiation (incident on the collector surface)
Ambient Temperature
Ambient Relative Humidity
Collector Inlet Temperature
Collector Outlet Temperature
Drying Bin Inlet Temperature

The airflow supplied for grain drying was assumed to be constant during the drying season, and was measured using an Alnor Velometer air velocity meter. The parameters listed above were recorded for the time period October 1, 1981 through June 15, 1982. The parameters were then recorded for another period during the fall of 1982 when detailed analysis of the solar collector performance characteristics was done.

The Solar System Performance

The performance characteristics of the solar collector when used for drying grain were estimated using data collected during the fall of 1982. The following information was recorded or calculated for the solar attic collector system:

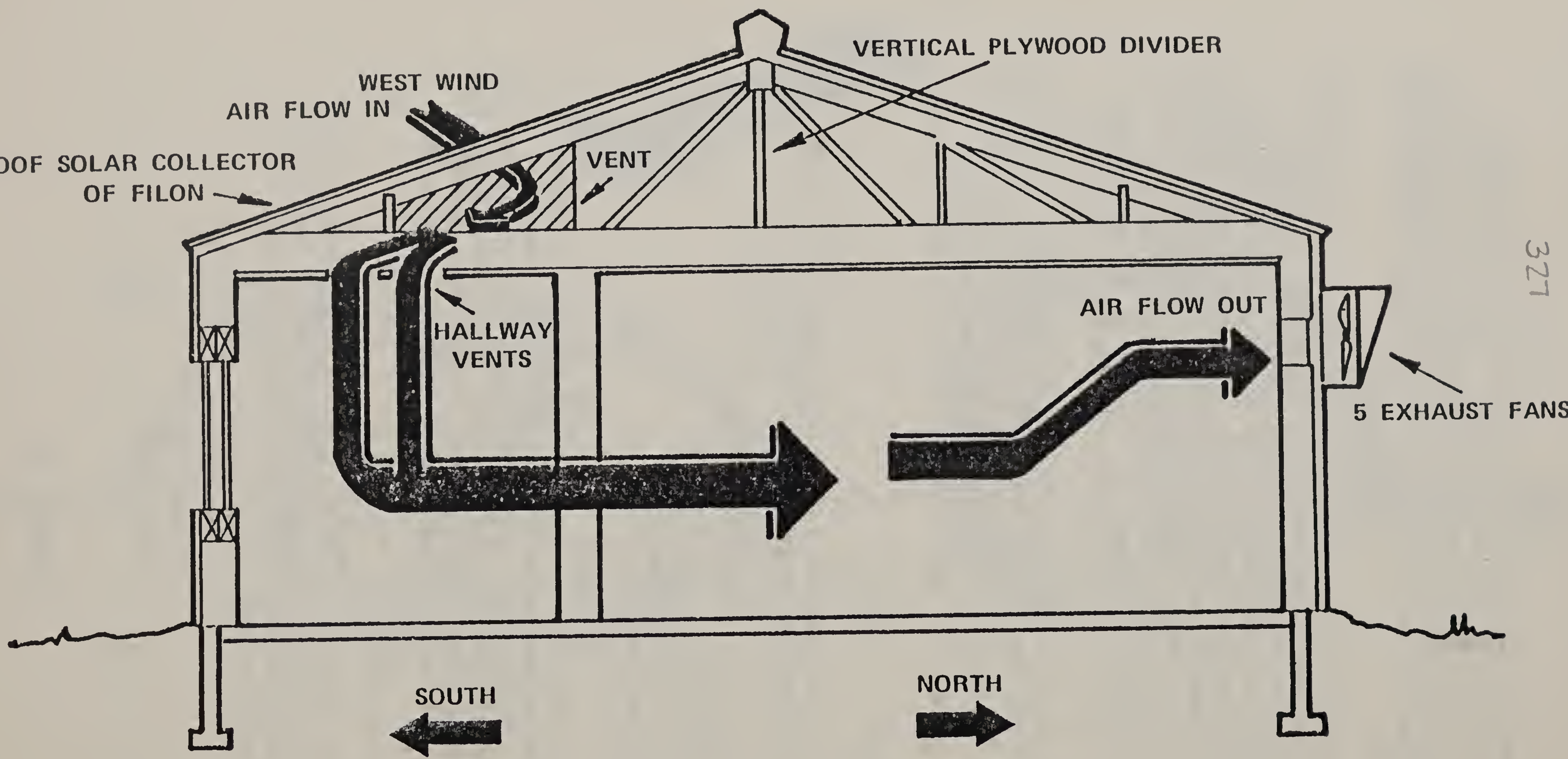

FIG. 2: SECTION OF THE OFFICE/LIVESTOCK BUILDING ON THE KEMPTON FARM, INDICATING AIRFLOW.

Drying airflow	13,032 cfm
Incident solar radiation (on collector surface)	486,705 btu/hr
Total solar gain	138,711 btu/hr
Average efficiency	28.5 percent

Based on this data, the break-even investment for this solar energy facility is in the range of $0.47 - 0.72 per square foot of collector. When considering solar heat versus other heat sources for crop drying, this cost must be considered in addition to the potential savings in capital equipment if no other heat producing device is included in the system, the potential return for additional space heating uses, and any applicable tax credits (state and federal).

Commentary

The Kemptons like their solar collector system for heating the office and farrowing units. However, they do not feel that the time and effort required for utilizing the solar collector for grain drying are cost effective. Part of the problem is the required manual labor of connecting the air ducts from the end of the building to the grain bin (30 - 40 feet away). However, the collector was not expensive to add to the building, and is working fairly well in supplementing the heating needs of the farrowing and nursery units.

SOLAR ENERGY for FARMSTEAD HEAT APPLICATIONS
The Thomas Kendle Farm

Thomas Kendle, a cash crop/livestock farmer in southwest Michigan constructed a portable solar collector system in 1980 for drying corn and soybeans. Mr Kendle agreed to cooperate with the Agricultural Engineering Department and the Cooperative Extension Service of Michigan State University in evaluating the performance characteristics and economic feasibility of this solar system.

The Farm

Thomas Kendle's farm is located at 70254 Sherman Road, Edwardsburg in Cass County, Michigan. The farm contains approximately 360 acres available for cropping with 71, 91 and 197 acres devoted to growing wheat, soybeans and corn, respectively. The solar system was used in 1980 to help dry all the harvested corn grains from about 20% moisture to 15% moisture.

There are 8 bins clustered together on the farm, with the two bins used for solar drying located at the ends as illustrated in Figure 1. The soybean bin at the southern end has a diameter of 14 feet, an eave height of 18 feet and is capable of holding 1400 bushels of soybeans. The corn bin at the northern end has a diameter of 24 feet, an eave height of 18 feet and is capable of holding 6500 bushels of corn. A fan capable of delivering air at 1870 cfm is mounted on the soybean bin while a 24 inch axial fan with a 7-1/2 HP fan, capable of of delivering 16,600 cfm at zero static pressure is mounted on the corn bin.

The Demonstration Goals

1. To measure the amount of incident solar radiation that could be collected at the farm over a total drying season.

2. To estimate the performance characteristics of the plastic bag solar collector system.

3. To estimate the economic feasibility of the plastic bag solar collector system under Michigan conditions.

The Collector System

The solar collection unit installed on the farm consists of two identical collectors joined together. Each collector is known as the Solar Park Air Handler (Model AH 8-12) and is manufactured by Chicago Solar Corporation, 2001 Highway 3 North, Fairbault, Minnesota. Each unit is rectangular in shape and is an air-supported collector in which the air also serves as the heat exchange medium. The single air channel under the absorber plate of each collector transports the heated air. Two other air channels provide insulation from ambient conditions. These airbags are deflated when the solar unit is not is use.

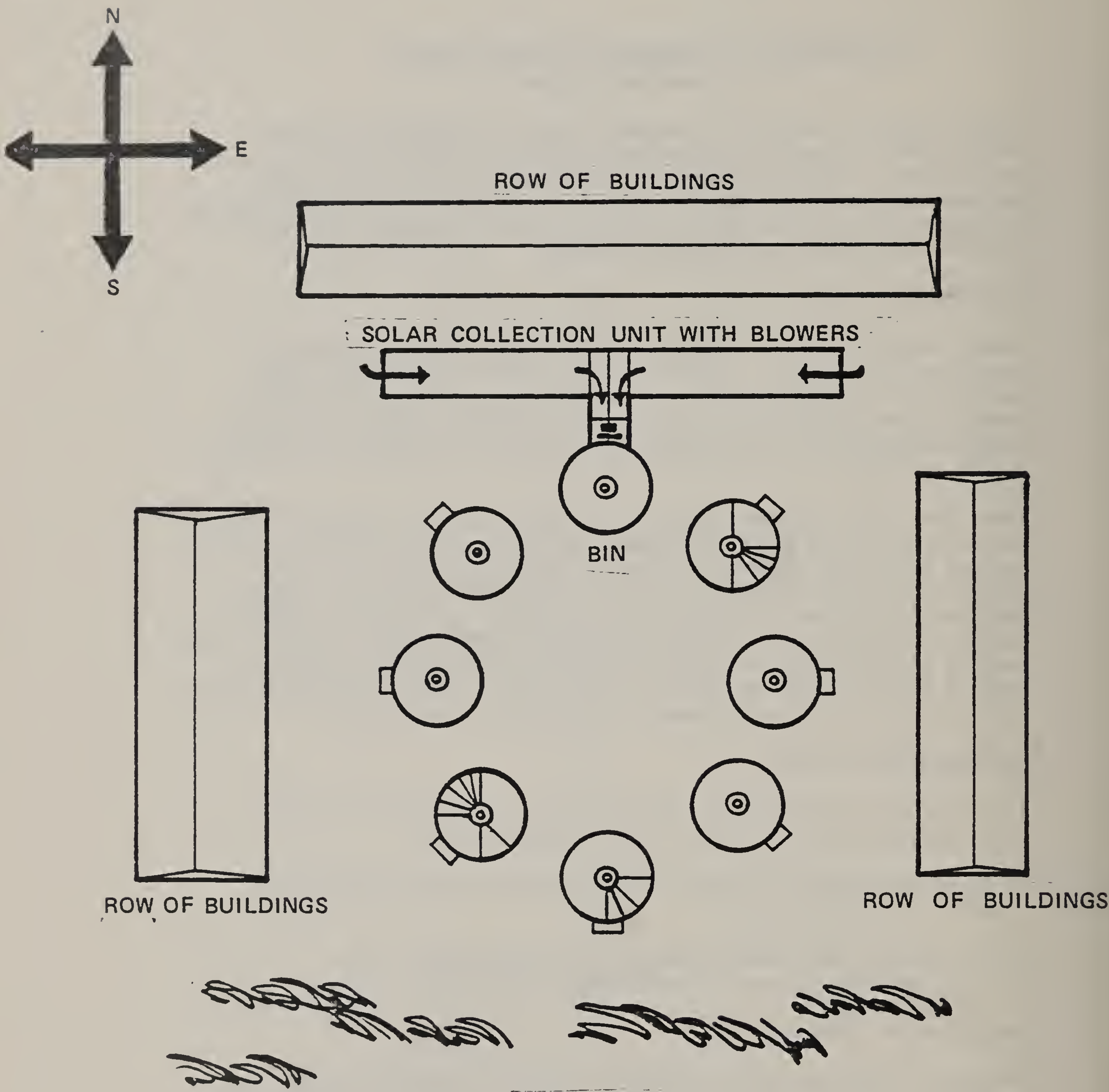

FIG. 1: SCHEMATIC LAYOUT OF THE BUILDINGS ON THE KENDLE FARM.

Each collector is 12 feet long and 8 feet wide and is connected to a 525 cfm fan. The two fans of the solar collector system combine to provide 1050 cfm of solar heated air which is then ducted to the drying bin. The airflow provided by the collector is less than the airflow capacity of the fans mounted on the drying bins. The difference in airflow is made up by drawing in ambient air.

The cover plates, absorber surfaces, back and side plates of each collector are plastic materials. It is recommended by the manufacturer that the solar system be used between the months of October and April of the subsequent year. The solar collectors were mounted to a frame built an an old house trailer chassis. They are used primarily for crop drying, although the system is portable. Mr. Kendle has had some problems with the plastic material maintaining integrity from one year to the next. This is probably a result of leaving the collectors out in the weather all winter even though they are not being used.

The Instrumentation

The solar site was equipped with a CR-21 data logger. The instrument recorded hourly averages of the parameters listed below:

- Solar Radiation (incident on the collector surface)
- Ambient Temperature
- Ambient Relative Humidity
- Collector Inlet Temperature
- Collector Outlet Temperature
- Drying Bin Inlet Temperature

The airflow supplied for grain drying was assumed to be constant during the drying season, and was measured using an Alnor Velometer air velocity meter. The parameters listed above were recorded for the time period October 1, 1981 through June 15, 1982. Due to problems with the solar collectors in the fall of 1982, they were not used for grain drying and consequently no data is available for estimating performance characteristics.

The Solar System Performance

The problems experienced with the plastic solar collectors in the fall of 1982 resulted in no data being available for performing a detailed analysis of the performance characteristics. Mr. Kendle feels that the air bag solar collector does have a fairly high efficiency. He did observe that in previous years the temperature of the air exhausted by the solar collector units on a sunny day ranged from 80 - 140 degrees F.

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SOLAR HEAT FOR GRAIN DRYING
(Demonstration Project)

FINAL REPORT

Submitted by
Cooperative Extension Service
University of Missouri
200 Agricultural Engineering Building
Columbia, Missouri 65211

PROJECT OVERVIEW

The University of Missouri, in cooperation with USDA, USDOE and 7 farm cooperators received a $255,397 grant in the spring of 1981 to install several demonstration solar grain drying systems in Missouri. The funds originated from three sources: 40% from USDA and USDOE, 40% from the University of Missouri Extension Division, and 20% from the farm cooperators.

The demonstrations were placed strategically throughout the state to serve as pilot systems. Each was designed to fit the needs of the farm involved and all were instrumented so that performance data could be obtained. The economic consequences of the investments were evaluated.

The sum of the areas of all the collectors was 4422 ft^2 with average cost of $7.36/$ft^2$. Cost ranged from $3.07/$ft^2$ to $39.68/$ft^2$. The all-day collector efficiency ranged from 29.2% to 70.3%.

Secondary uses for the solar collectors included, shop heating, pre-heating ventilation air for swine housing and home heating. One of the systems used to pre-heat air for swine housing included a rock heat storage unit.

The results have provided some specific design data and experience in the use of solar collectors to provide heat for grain drying. Data was also collected to give design parameters when multiple use of a collector is desired.

The demonstrations have generated interest for the use of solar heat in agriculture in each of the geographic areas.

The project was terminated a year early which resulted in parts of the evaluation and educational activities not being completed. A training session for Missouri Area Agricultural Engineering Specialists has been given on solar grain drying designs. Three programs for farmers and vocational agriculture Young Farmers groups have been held. A meeting has been scheduled for January 1983 that consists of 4 sessions, each 2 hours in length.

MISSOURI SOLAR GRAIN DRYING DEMONSTRATION SUMMARY

NAME	SQ.FT.	COST $/ft^2	CFM/ft^2	ALL-DAY EFF.%	++DISTRIBUTION DUCT TYPE	LG.FT	% LOSS	BU. DRIED	PAY-BACK YRS. 0% Rtn	10% Rtn
Kliethermes	1440	3.07	6.39	60.6	Plastic	120	10-20	30,000	5.5	7.5
Gerber	288	5.36	5.39	61.7	Plastic	35	17.4	14,400	2.0	2.5
Cline(1)	576	5.05	4.69	70.3	Nylon	30	---	16,000	3.5	4.3
Clark(1)	576	6.07	5.22	67.0(2)	Nylon	30	---	20,450	---	---
Hoerr	192(3) 224(4)	12.50 19.18	1.01 4.95	28.0 68.0	Nylon "	50 "	---	25,000 "	5.6 "	8.0 "
HARNESS	160(5) 126(6)	10.02 39.68	1.62 1.80	29.2 32.5	Flex ins.	30	---	11,690	10.5	20.0
Tiemeyer	840	8.21	---	---	---	--	---	35,200	---	---

(1) Selective Paint
(2) Instantaneous efficiencies
(3) Commercial collector-Solar Search,Inc. Model "B"
(4) Commercial collector- Solar Search, Inc. "Triangular plate"
(5) Commercial collector- Sunduit,Inc. Model "B"
(6) Commercial collector- Solar Resources, Inc.

CONCLUSIONS

1. Grain drying systems utilize any heat added to the drying air. Collector efficiencies and total BTU transferred are greatest with high air flow rates--5 to 10 cfm/ft^2 of collector area. Collector systems specifically designed for grain drying (high air flow rates and small temperature rises) might not be suitable for other applications, i.e. preheating ventilation air or heating air for shops.

2. A collector system designed for grain drying and alternate uses should consider the requirements for each use. The air flow rates for grain drying are typically high while those for preheating air for livestock ventilation are low. Space heating, shop and home heating require high temperature rises in the collector; grain drying systems do not.

3. A modified suspended plate design was selected for applications involving both grain drying and space heating. The collector was modified to allow air flow on both sides of the absorber plate for grain drying. The intake area to the air channel above the plate is closed to give high temperature operation for space heating. Special consideration has to be given to air channel velocities for each of these conditions.

4. The distribution of heat from the collector to the point of use requires careful consideration. The cost of 30-40 ft lengths of plastic or nylon cloth tubing is low, but heat losses range from 10 to 20% of the collector output. Flexible insulated ducts are expensive, offer high resistance to air flow and deteriorate rapidly when used outdoors. Rigid insulated ducts of proper sizes are expensive. The cost of heat distribution can make the system uneconomical.

5. Plenum ducts should be used for putting air into and taking air out of the collector channels. Resistance to air flow is high in small inlets and outlets. Most of the commercial collectors tested had such high resistance to air flow that it was impossible to get the higher air flows necessary for efficient collector performance.

6. When collectors are operated under a negative pressure, air leaks do not cause as great an energy loss as air leaks do when collectors are pressurized.

7. Fans selected for use on collectors should be checked for actual performance. Molded aluminum blade fans manufactured by one company delivered 50 and 60% of their published ratings.

8. Selective paint on the front side of the absorber plate with regular flat black on the back side gave 10% higher efficiencies compared to a similar unit having only flat

black paint on the absorber. The units compared were operating with high air flows and large temperature rises. It is expected that the difference would be greater if low air flow rates were used.

9. The performance of collectors was affected by dirt accumulations from farming and hog lots. Some type of filter material should be used on the collector inlets.

10. A rock-heat storage design procedure was developed for this project. The method and data are included in the Appendix.

11. Hourly performance data on collectors are variable. A method to analyze and evaluate this data was developed. The procedure is described in the Appendix.

12. Money should not be invested in any solar system until an economic analysis is completed. Simple payback analyses are useful, but with energy costs escalating, more refined analysis is required. A general rule is that the savings generated for one year should be equal to or greater than 20% of the proposed investment.

The investment/savings ratio (I/S) of the proposed system can be calculated. The following equation was developed to evaluate the I/S ratio and includes an energy escalation rate.

$$I/S = \frac{(1+e)^n - (1+i)^n}{(e-i)(1+i)^n}$$

I/S = dollars invested per dollar saved
i = rate of return on investment (%)
e = energy escalation rate (%)
n = years payback

Robert M. George

Robert M. George, Extension
Agricultural Engineer

Donald B. Brooker

Donald B. Brooker
Department of Agricultural
Engineering

Co-Project Directors

INSTRUMENTATION

Data Collection

All data were recorded on a Sym-based data logger. This unit was developed at Kansas State University. The units have 32 analog channel inputs, 8 digital inputs, and 2 frequency counting inputs. All inputs are sampled at one second intervals and integrated for the final recorded data. The data is recorded on cassette tape.

Temperature

All temperature measurements were made with AD590 integrated circuit sensors. The output of these devices is extremely linear with temperature.

Solar Radiation

The radiation data were taken with LiCor silicon pyranometers (LI-200-S). All measurements were made in a plane incident to the collector surface.

Air Flow

Air flow for calibrating the collector systems was measured through orifices. Velocity profiles were obtained with a J-Tec velocity meter. The J-Tec meter operates on a Vortex-shedding principle and gives digital output that has been averaged over 15 to 30 second sample times.

A heated element air velocity device with analog output was developed to monitor variable air flow rates. This instrument was needed because air flow rates into the swine housing and from rock heat storage is variable.

Data Processing

The data recorded with the data loggers was processed through a reader directly into an Apple II computer system.

KLIETHERMES DEMONSTRATION

I. Steve Kliethermes, Route 2, Bunceton, MO, operates 800 acres of cropland with three brothers. Steve's efforts are all concentrated with cash grain production.

II. The objective of this project was to demonstrate how an existing building can be modified to serve as a solar collector to provide supplemental energy for grain drying with an in-bin continuous flow dryer.

III. The solar collector was retrofitted into the roof of an old barn and attached shed approximately 100 feet from the drying bin. The barn roof area is 840 square feet and the shed roof area is 600 square feet, a total of 1,440 square feet of collector.

The original roofing material was removed and replaced with filon fiberglass cover plate. The bottom of the rafters were covered with TF-600 rigid insulation board. The rafters and insulation back were painted with roofing tar for the absorber surface.

The air channels formed between the cover plate and insulated back were 4 in. deep on the barn roof and 6 in. deep on the shed. Air enters the collector under the peak of the barn roof and from the outside edge of the shed roof. This air is collected in an insulated duct constructed at the valley formed where the shed and barn roof meet. A 24 in. fan at the end of this duct forces the heated air through a plastic suspended overhead tube 120 ft to the drying fan.

The storage and drying system consists of 33,500 bu. storage, a dump pit and leg, and 7.5 HP fan with a continuous flow high temperature bin drying system (Cir-cu Flow).

IV. The collector system cost was $4,416.68. This is $3.07 per sq ft of collector.

V. The all day efficiencies of this collector varied from 60.6% to 48.3%. The air flow was 9,200 cfm or 6.39 cfm/ft^2. The system was completed and operated in the fall of 1981. The all day efficiency was 60.6%. Wheat was dried in July '82, and the collector efficiency was 48.3%. The insolation values are almost equal for July and October for this collector. There was an accumulation of dirt on the collector during July '82 which explained the difference in performance. The collector was washed before fall operation. The efficiency during fall operation returned to 58.6%.

A radiation meter was used to measure values incident to the cover and then placed under the cover to determine the difference in values in October 1982. The cover plate had a transmittance of .704I when dirty and .813I after being cleaned. This represents a change of 10.9%.

The heated air from the collector was conveyed to the grain drying fan 120 ft away by a 30 in dia. plastic tube suspended by a winch and cable over the driveway. The temperature drop from the collector to the fan varied from 2 to 4 degrees F. depending on the wind velocity. This represented a loss of 10 to 20% of the collected heat.

TABLE 1

Full Day Collector Performance Data[1]

Date	Average $\Delta T_c/I$	All Day Efficiency (%)	Average Temp Rise (^oF)
Fall '81	.091	60.6	19.1
July '82	.072	48.3	15.1
Fall '82	.088	58.6	18.5

[1]Airflow = 6.39 cfm/ft^2
Av. Insol (I) = 210 BTU/hr/ft^2
ΔT_c (^oF) = Collector Disc Temp - Ambient temp

The dryer is operated with a drying air temperature of 130^o F. The solar collector furnished 65% of the heat requirement during daytime operation. The solar heat accounted for 27% of the heat required for a 24 hr day, when solar energy was available. The solar input accounted for 17.6% of the seasonal heat requirements for drying.

TABLE 2

Bushels Grain Dried

Yr	Bu	Grain	Initial Moisture
1981	16,500	Shelled Corn	30% to 22%
1981	17,000	Milo	24% to 18%
1982	15,000	Wheat	25% to 21%
1982	15,000	Shelled Corn	30% to 21%

VI. (Data and illustrations are shown on pages that follow.)

VII. This demonstration provides solar heat to a high temp in-bin continuous flow drier. A preliminary analysis of this type of application shows that the solar heat can only be a low percentage of the total heat requirement.

The collection duct in the barn had some air leaks. These leaks were not obvious in the test data. The static pressure drop in the collector system was .08 in. and the infiltration was a low percentage of the total air flow.

The collector air channels were 4 in. and 6 in. deep resulting in low channel air velocities. Better performance would have been expected if channel depth were reduced, thus increasing air velocity. Insulation material at the bottom of the air channels would not only conserve energy but also increase velocity.

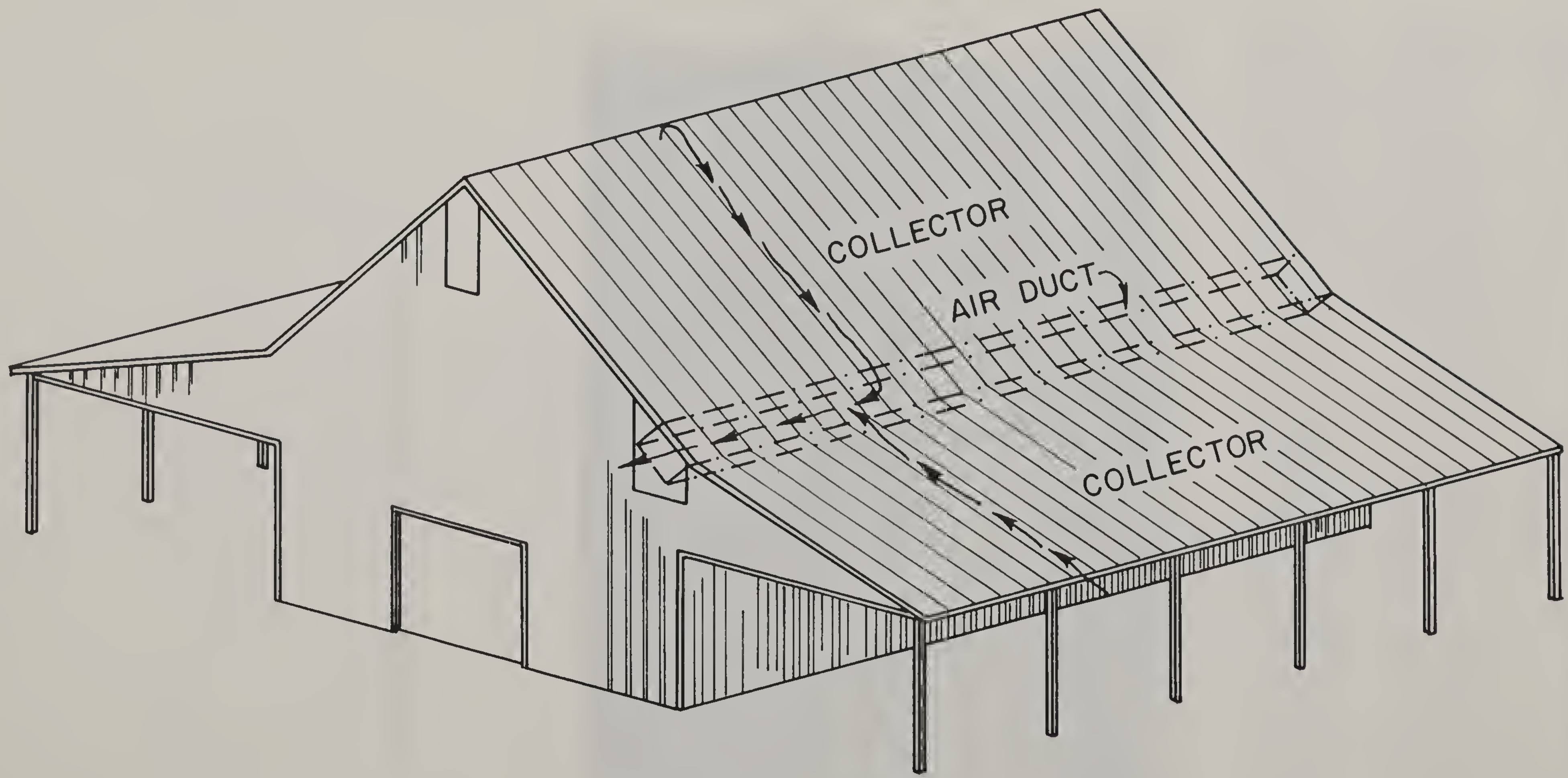
The investment in this system was \$4,416. A seasonal savings of 17.6% for fuel amounted to \$706/yr on 33,500 bu.

$$\frac{\text{Investment}}{\text{Savings}} = \frac{\$4{,}416}{\$\ 706} = 6.25$$

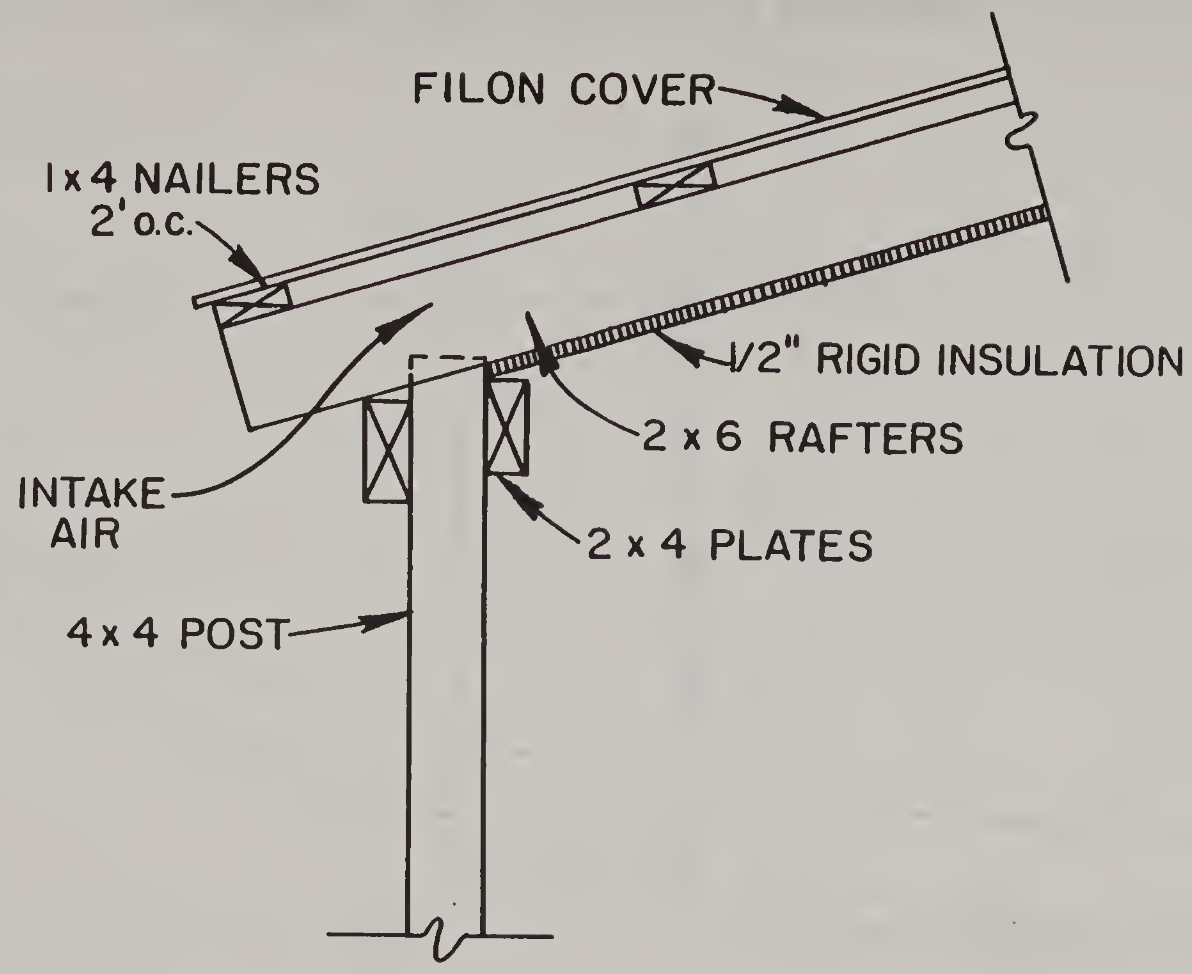
assuming an energy escalation rate of 10%:

5.5 years based on 0% return on invested money;
7.5 years based on 10% return on invested money.

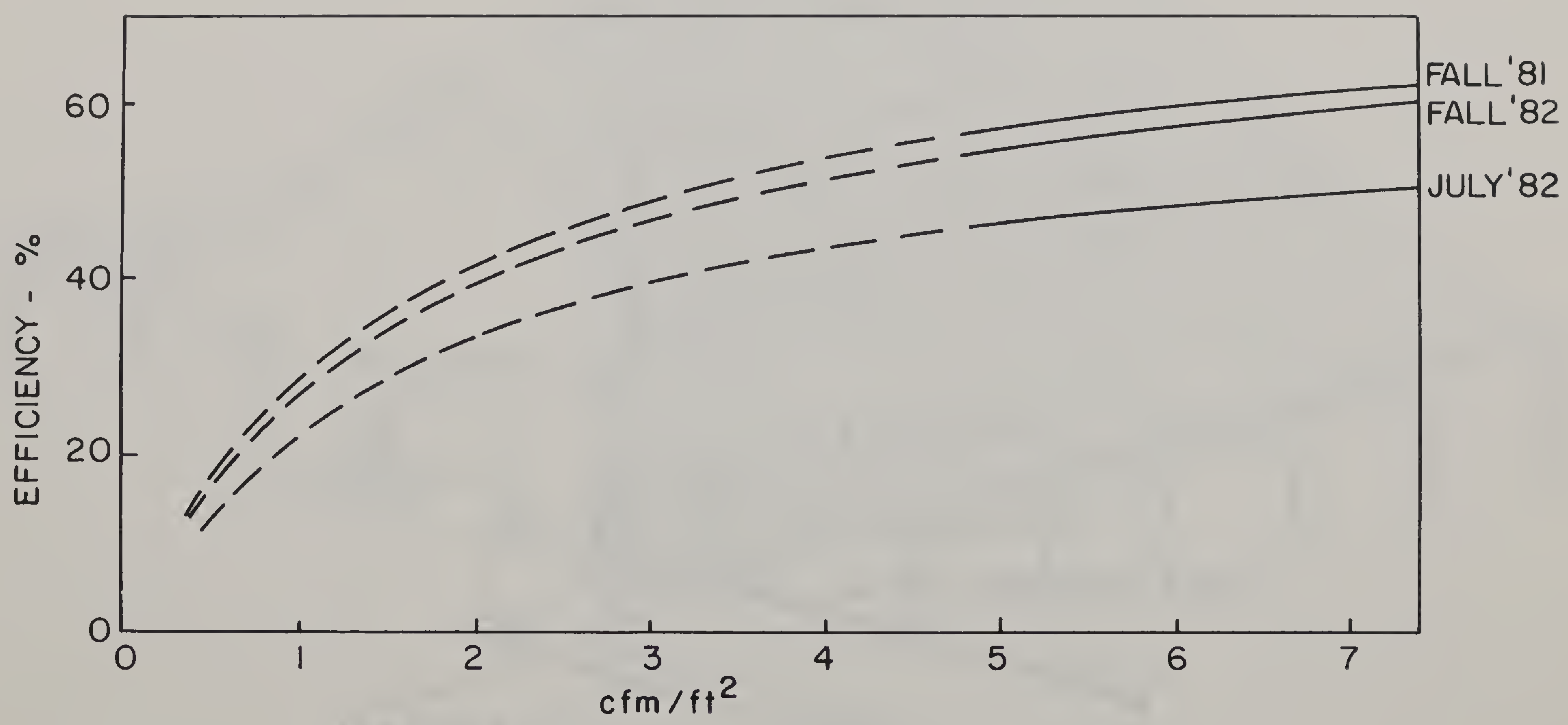
KLIETHERMES SOLAR COLLECTOR SYSTEM



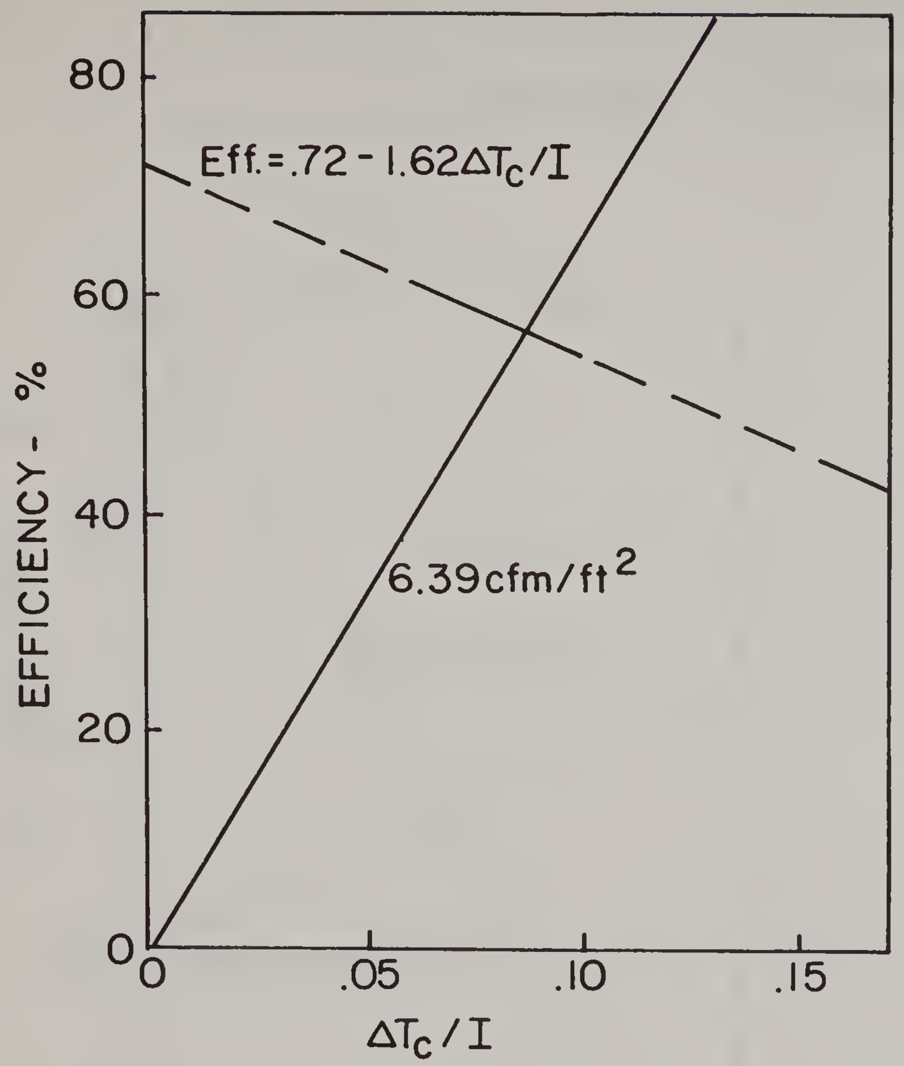
AIR FLOW FOR BARN ROOF COLLECTOR

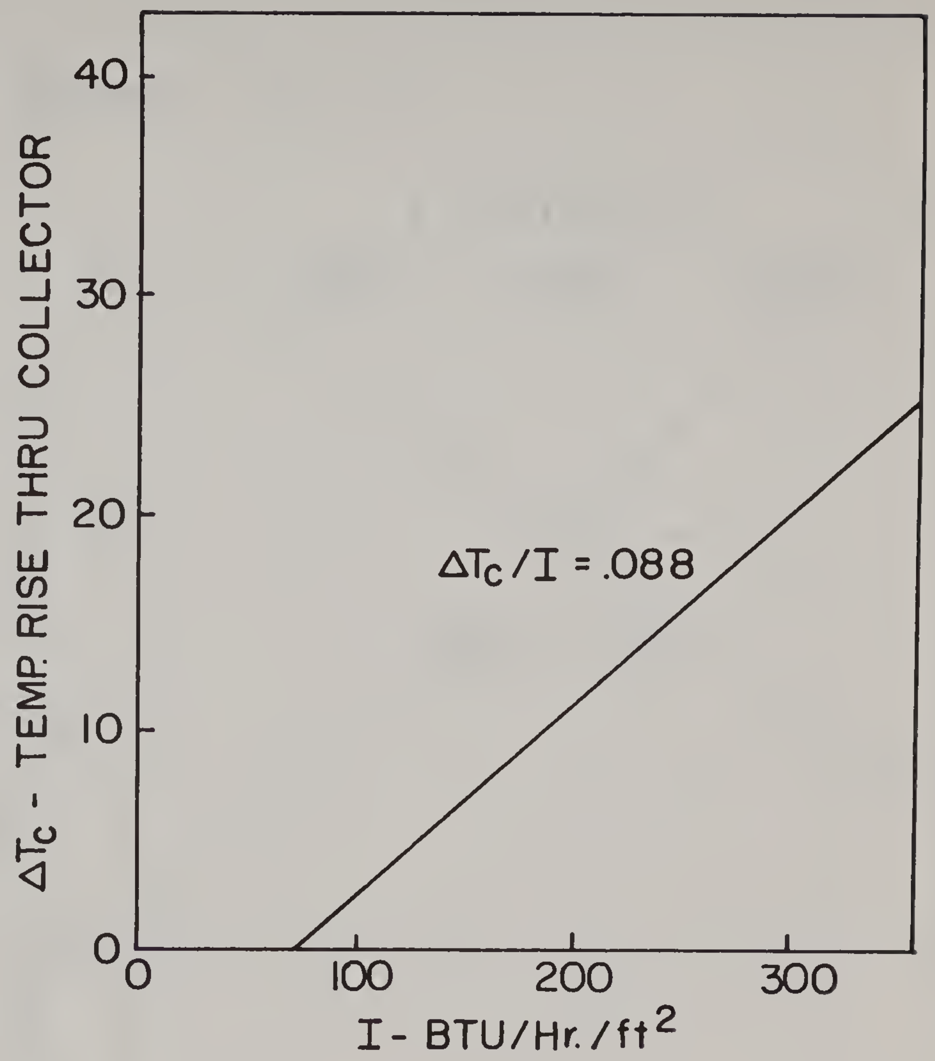


SHED ROOF COLLECTOR CROSS-SECTION

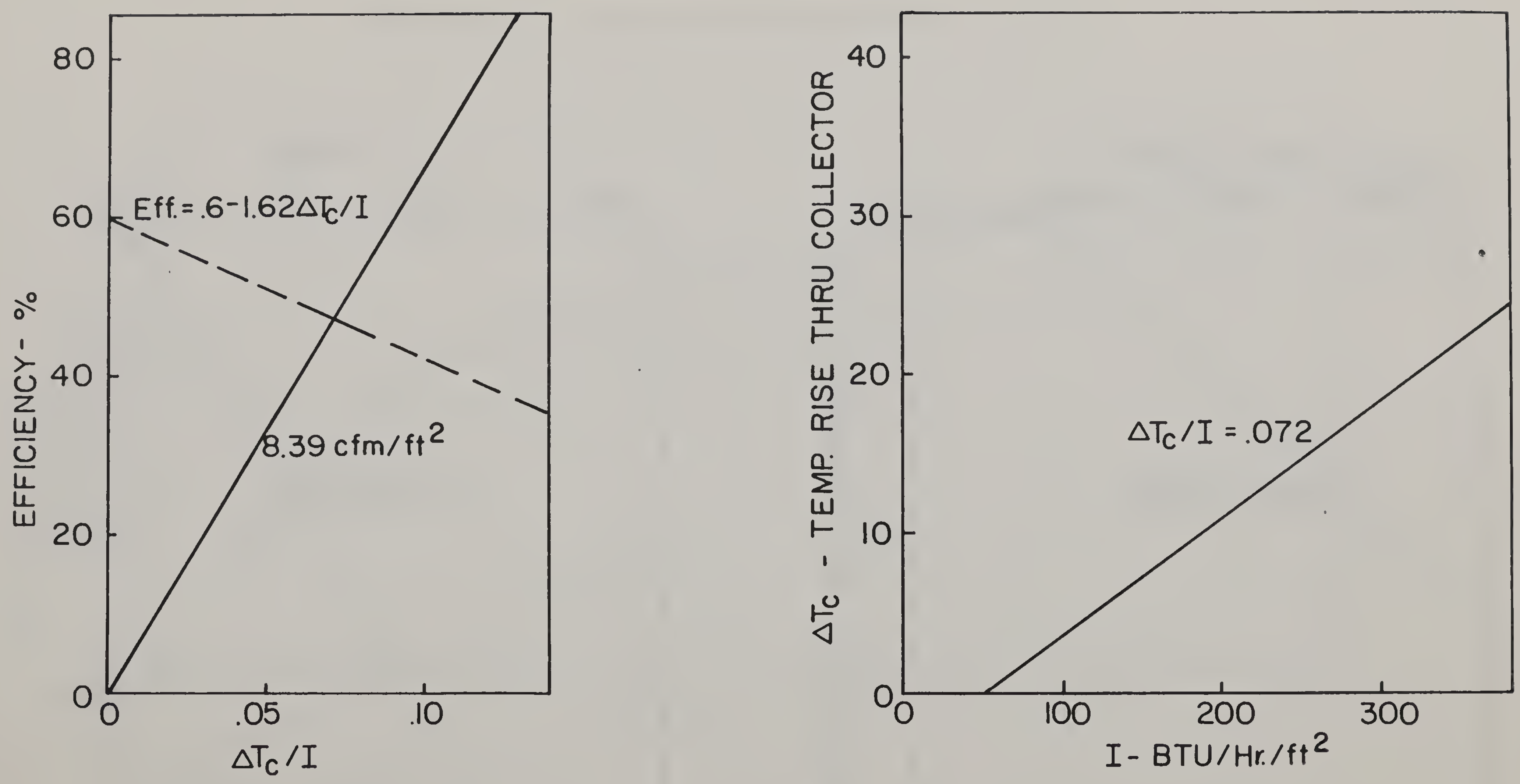


KLEITHERMES - FULL-DAY COLLECTOR PERFORMANCE

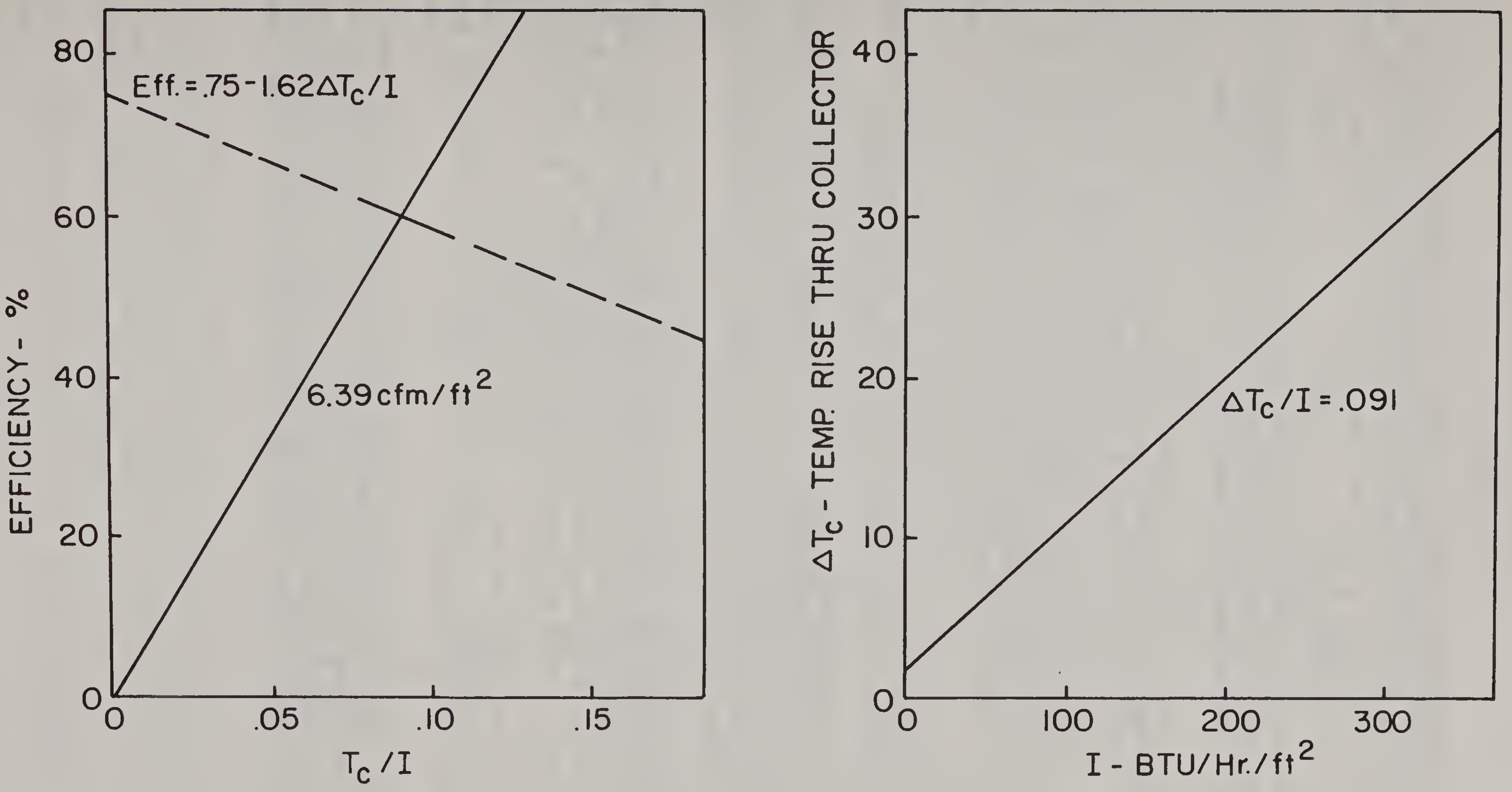




KLEITHERMES - FULL-DAY COLLECTOR PERFORMANCE - FALL '82



KLEITHERMES - FULL-DAY COLLECTOR PERFORMANCE - JULY '82



KLEITHERMES - FULL-DAY COLLECTOR PERFORMANCE - FALL '81

GERBER DEMONSTRATION

I. Melvin Gerber, Route 1, Box 156, Versailles, MO 65084, operates a 400 acre combination grain and livestock farm. Crops include corn, grain sorghum, soybeans, and wheat. Livestock include a 70 sow farrow to finish hog enterprise and 30 beef cows.

II. The objective of this project is to demonstrate the dual use of a portable collector for drying grain and for furnishing supplemental heat to a farrowing house.

III. The 12 x 24 ft portable collector is of a suspended plate design. Air flow is horizontal through the 24 ft length. An 18 in 1/4 HP fan exhausts air from the collector. The typical suspended plate design has been modified so that air is flowing on both sides of the absorber plate when a low temp rise is used for drying grain. The air inlets to the channel above the absorber plate can be closed to provide higher temp air for farrowing house heating.

The collector plate is painted with flat black paint. The back side of this plate was prepainted white.

The collector is moved adjacent to the farrowing house for supplying supplemental winter heat and is connected to the ventilation system with a rigid insulated duct. The total variable winter ventilation air will be drawn through the collector and into the house.

When grain is dried, the heated air from the collector is discharged into the intake of the drying fan. The connecting plastic tube is 35 ft in length. There is an average of a 4^{o}F temperature loss from the collector to the fan intake. This represents a 17.4% loss of heat energy.

IV The completed cost of this collector was $1,543.49; a cost of $5.36/ft^2. Additional costs for ducting to the farrowing house was $404.

V. The air flow rate through the collector was 5.39 cfm/ft^2. The collector was operated with air flow under the absorber plate and also on both sides of the plate when collector performance data were taken. The data in the following table shows full day comparative performances.

TABLE 1

Full Day Collector Performance Data[1]

Mode	$\Delta T_c/I$	All Day Efficiency (%)	Average Temp Rise (^oF)
Air under plate	.106	61.7	22.3
Air on two sides	.113	65.7	23.8

[1]Air flow = 5.39 cfm/ft^2
Av. Insol (I) = 210 $BTU/hr/ft^2$
ΔT_c (^oF) = collector disc temp - Ambient temp

The output of the collector provided a 3.7° average temperature rise in the drying air.

Mr. Gerber's farm records show he harvested and dried the following crops in 1982:

Month	Grain	Initial Moisture (%)	Bu
June 25	Wheat	30	400
July 1	Wheat	18	180
July 2	Wheat	15	1,420
Sept 11	Shelled Corn	30	300
Sept 21	Shelled Corn	22	500
Sept 22	Shelled Corn	21	1,500
Sept 23	Shelled Corn	20	1,250
Sept 23	Shelled Corn	21	1,000
Sept 24	Shelled Corn	21	1,250
Oct 1	Shelled Corn	18	2,000
Nov 5	Milo	19.1	2,000
Nov 8	Milo	20.2	1,500
Nov 9	Milo	18.7	1,500

The farm records for 1978, 1979, 1980 and 1981 show his LP gas use was .0825 gal/bu dried for shelled corn and milo. Based on past costs, shelled corn would have cost $450 and milo $288 for LP gas. There was no LP used and the entire gas cost of $738 was saved because of the solar collector.

No data are available for farrowing house heating. Estimates based on a collector efficiency of 17.5% at .97 cfm/ft^2 give a savings of $75/yr. Test data show the efficiencies might be approximately 30%, which would result in a greater than estimated savings.

VI. (Data and illustrations are shown on pages that follow).

VII. This system has performed better than expected. The efficiencies of the collector are higher than estimated.

The total air flow is disappointing. A Grainger 18 in dia-1/4 HP vent fan was selected for the collector. The air flow rate was measured at 1,550 cfm at .15 in S.P. The performance data published by Grainger show that the air flow should be 2,600 cfm at this pressure. The fan operated at 60% of its rated capacity.

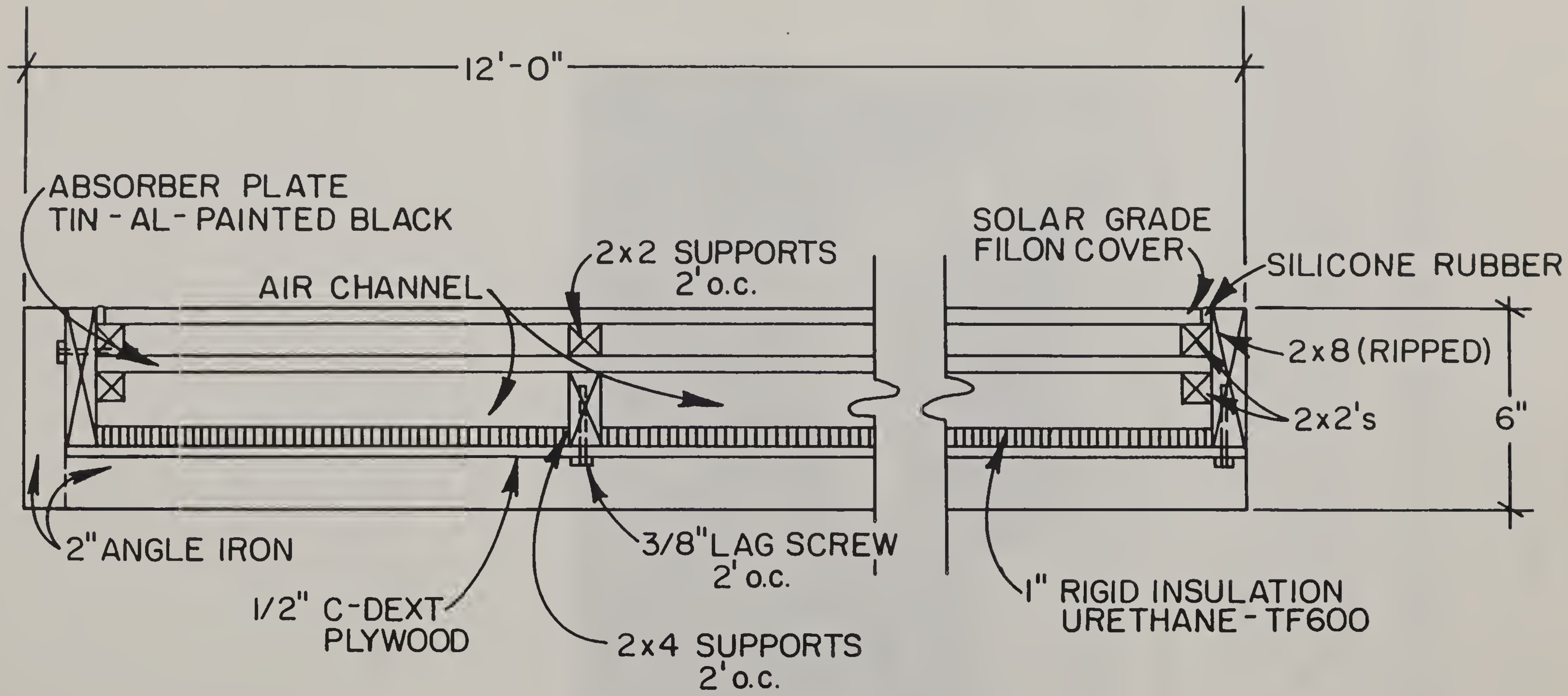
The investment in the collector system was $1,543.49. The savings on drying was $738/yr.

$$\frac{\text{Investment}}{\text{Saving}} = \frac{\$1,543.49}{\$\ 738} = 2.09$$

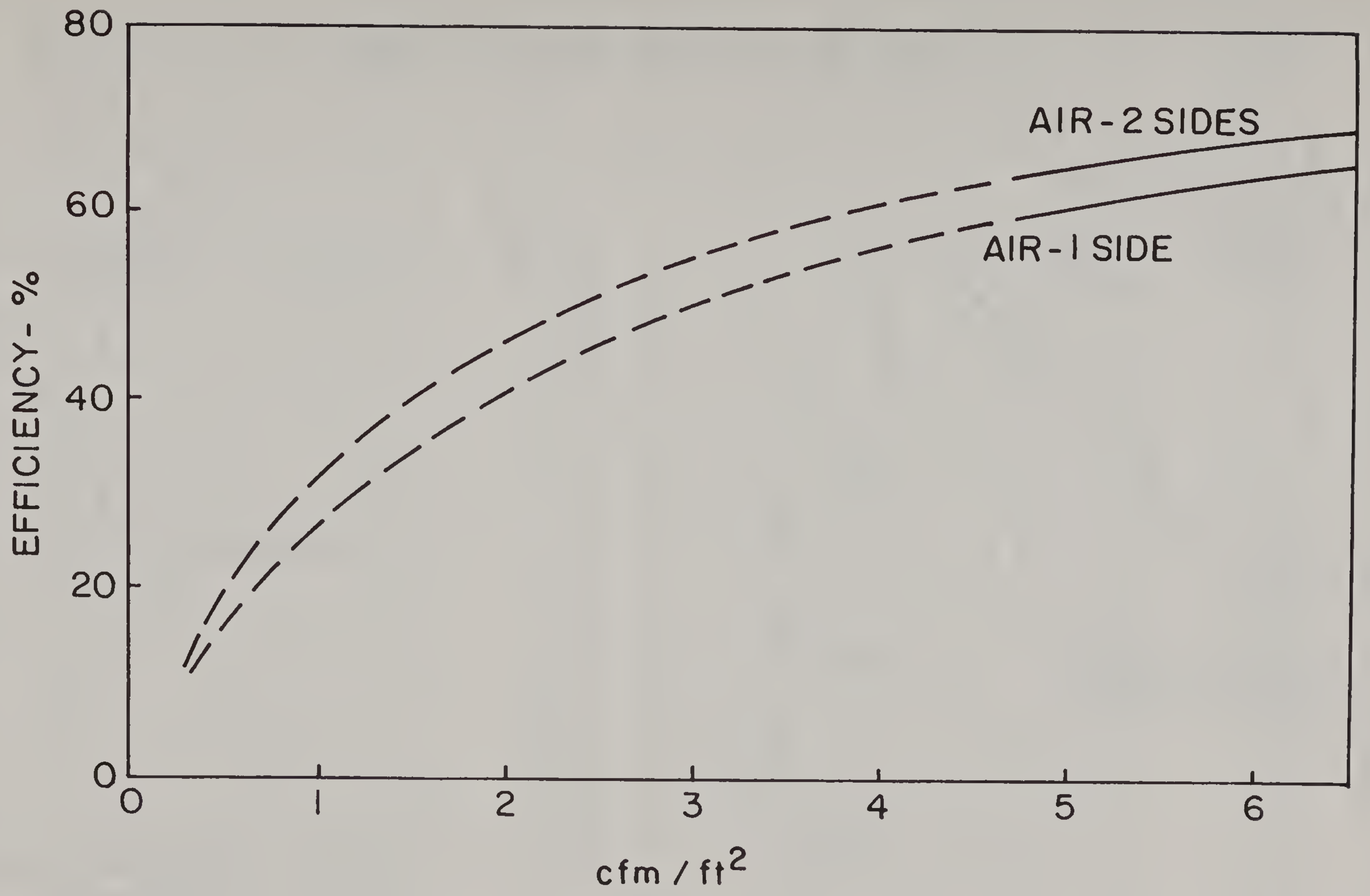
The payback assuming a 10% energy escalation rate is:

2 years based on 0% return on invested money;
2 1/2 years based on 10% return on invested money.

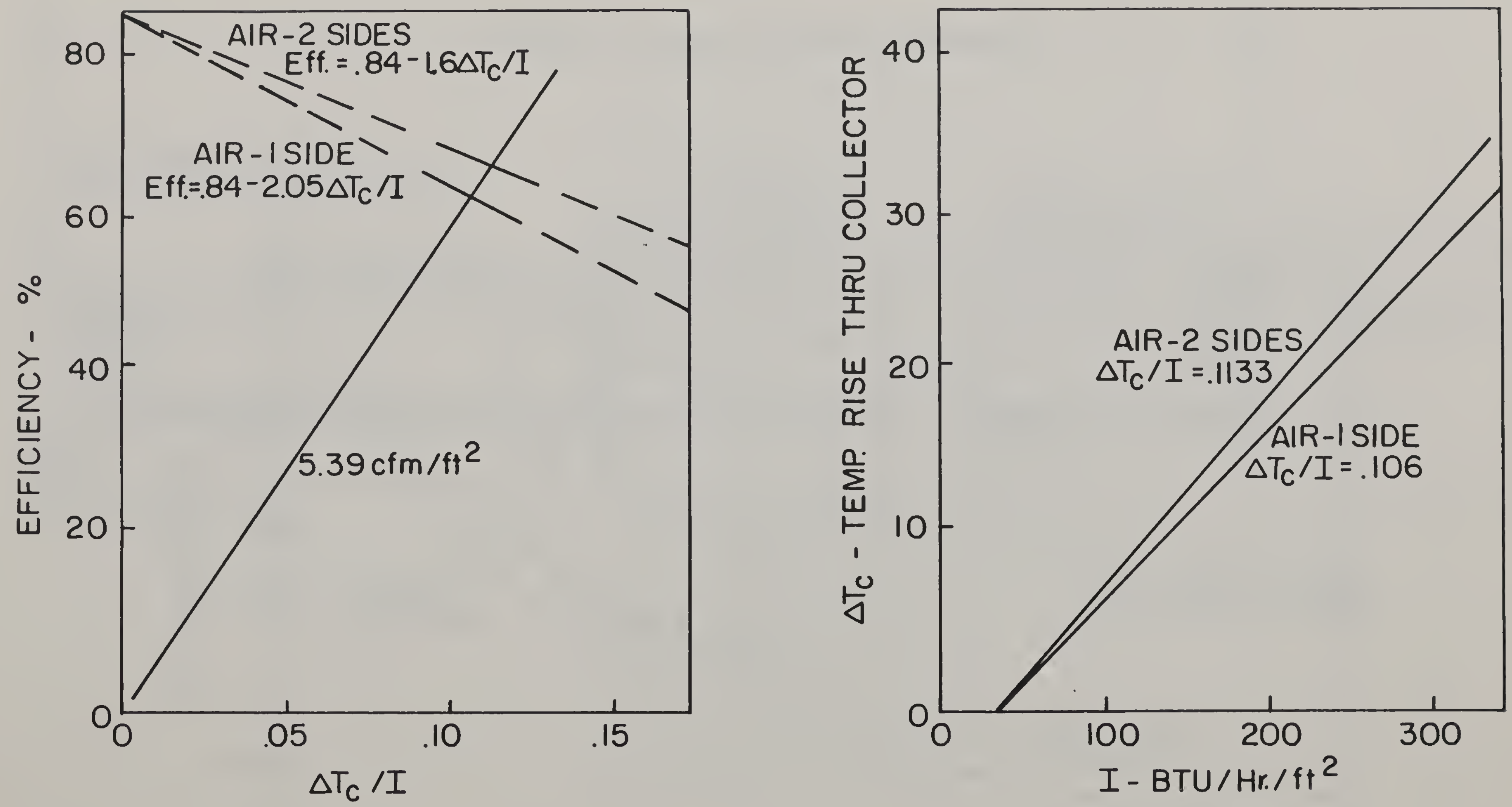
GERBER SOLAR COLLECTOR SYSTEM



END VIEW-COLLECTOR CROSS-SECTION



GERBER - FULL-DAY COLLECTOR PERFORMANCE



GERBER - FULL-DAY COLLECTOR PERFORMANCE

CLINE DEMONSTRATION

I. Victor Cline, Route 1, Shelbyville, MO, operates a 305 acre combination livestock and grain farm.

II. The system on this farm was planned to demonstrate the dual use of a solar collector that provides heat for grain drying as well as supplemental heat for a farrowing and nursery unit.

III. The collector system is constructed in two units. One is a 12 x 24 ft portable collector to use with grain drying. The other collector is attached to a rock storage adjacent to the swine units. Heat can be conveyed 75 ft from rock storage to the grain drying bins. The collectors are of a modified suspended plate design. A selective paint was used on the absorber plates. Air flows on both sides of the absorber plate when heat is provided for grain drying. The collectors are modified to allow air flow behind the plate to provide higher temperature air for the swine heating application. The collector and rock storage system are arranged so that heat from the collector can selectively go to the swine housing or into the rock storage. At night, heat is removed from rock storage by reversing air flow.

The drying system consists of a 7.5 HP drying fan and 24 ft dia. bin. A stirring device is installed in the drying bin.

IV. The investment in the 12 x 24 ft portable collector was $1,645. This is $5.72/ft^2$. The stationary collector on the rock storage cost $1,264 or $4.39/ft^2$. The rock storage cost $2,591.

V. The efficiency of this collector system was excellent. The construction was identical to that of the Gerber system with the exception that a selective paint was used on the front of the absorber plate. The back was painted with a metal flat black paint. The absorptivity of each paint was 0.92. The emissivity of the selective paint was 0.10. The emissivity of the regular flat black was 0.95. Improved performance was expected with this combination of paint over the Gerber system, particularly with a high temperature increase through the collectors. A marked difference in performance between the two collectors would not be anticipated at higher air flow rates. Data are not available for operation at high temperature increases.

An 18 in dia. 1/4 HP Grainger fan was used with this collector. The measured air flow was 1,350 cfm. This was only 52% of the expected output, 2,600 cfm, which was based on the manufacturer's data.

The test performance data are listed in Table 1.

TABLE 1

Full Day Collector Performance Data[1]

$\Delta T_c/I$	All Day Efficiency(%)	Average Temp Rise (^oF)
0.1416	70.3	29.7

[1]Air flow = 4.69 cfm/ft^2
Av. Insol (I) = 210 $BTU/hr/ft^2$
ΔT_c (^oF) = collector disc temp - Ambient temp

VI. (Data and illustrations are shown on pages that follow).

VII. The selective paint was responsible for a 7% increase in efficiency over the Gerber collector with each respective air flow rate.

Two thousand bu of shelled corn were dried in 5 days from 26% to 14% when the stirring device was used. The bin was refilled with 5,500 bu of 22% shelled corn and dried to 13% in 8 days (stirring device again used).

The collector tube was then switched to a second bin without a stirring device where 5,500 bu of 20% shelled corn was dried to 14% in 6 days. Three thousand bu of milo were also dried.

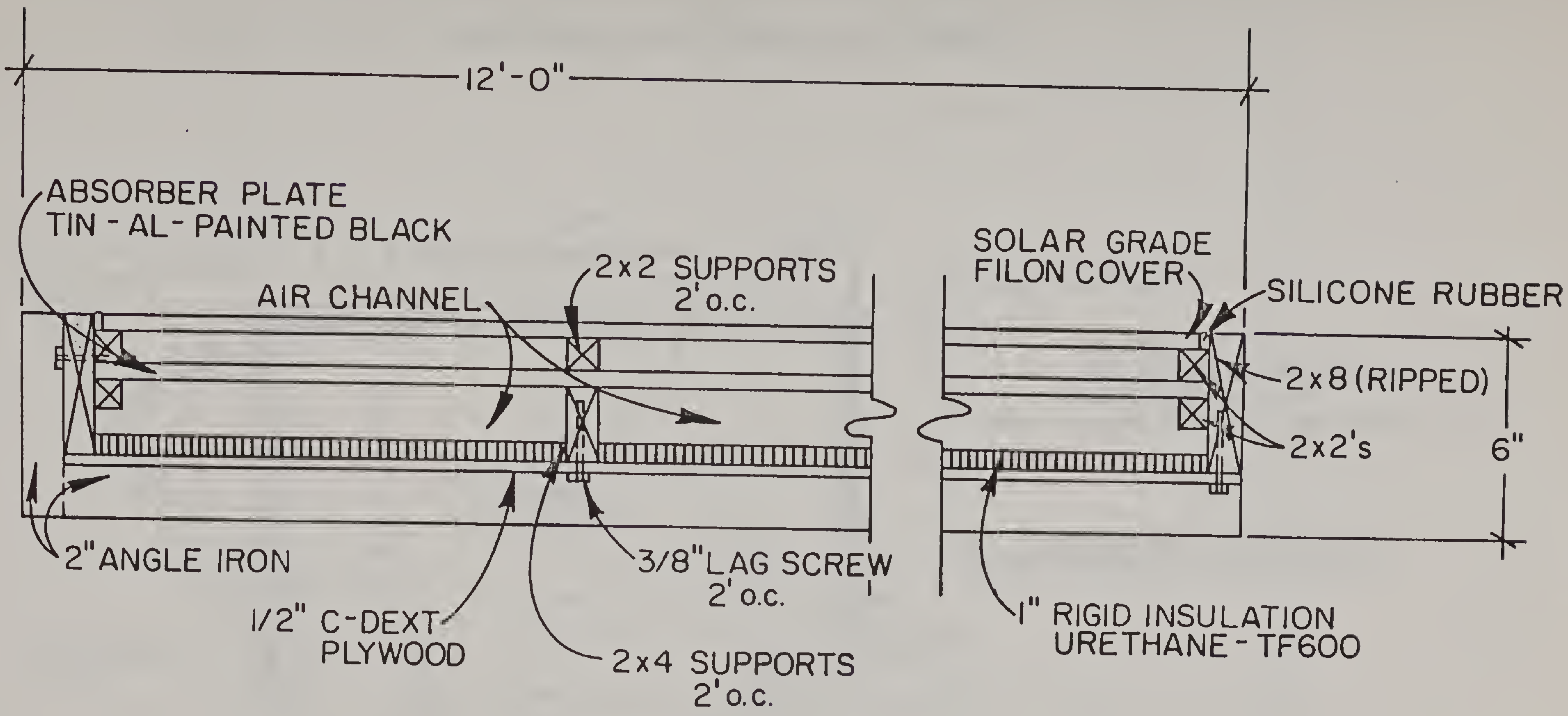
Normal LP gas and electricity costs were $575 for this drying operation. No LP gas was used this year. Electricity costs were $143. This amounted to a savings of $433.

$$\frac{\text{Investment}}{\text{Savings}} = \frac{\$1,645}{\$\ 433} = 3.8$$

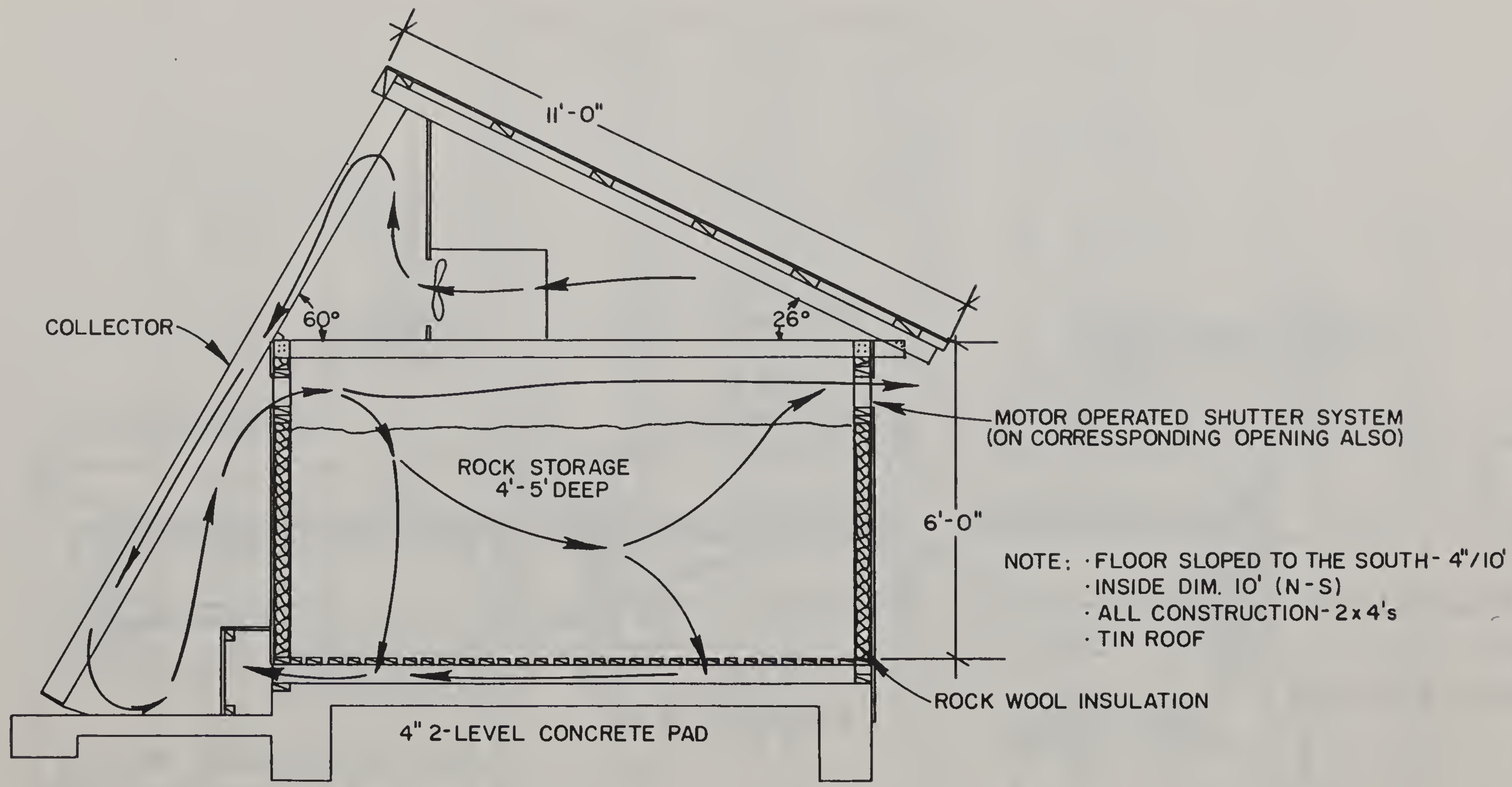
The payback assuming an energy escalation rate of 10% is:

3.5 years based on 0% return on money invested;
4.3 years based on 10% return on money invested.

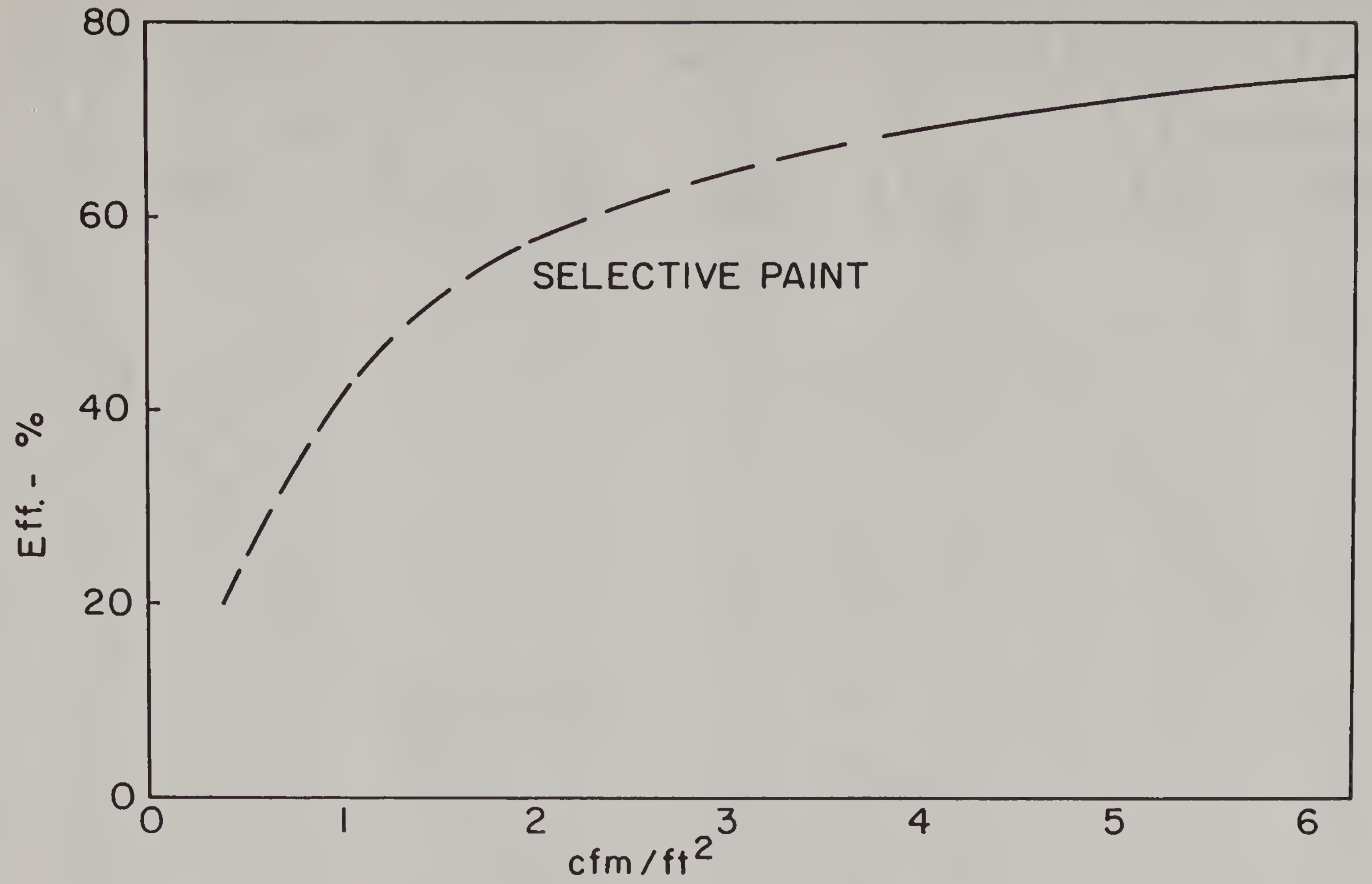
No data are available on swine house heating.



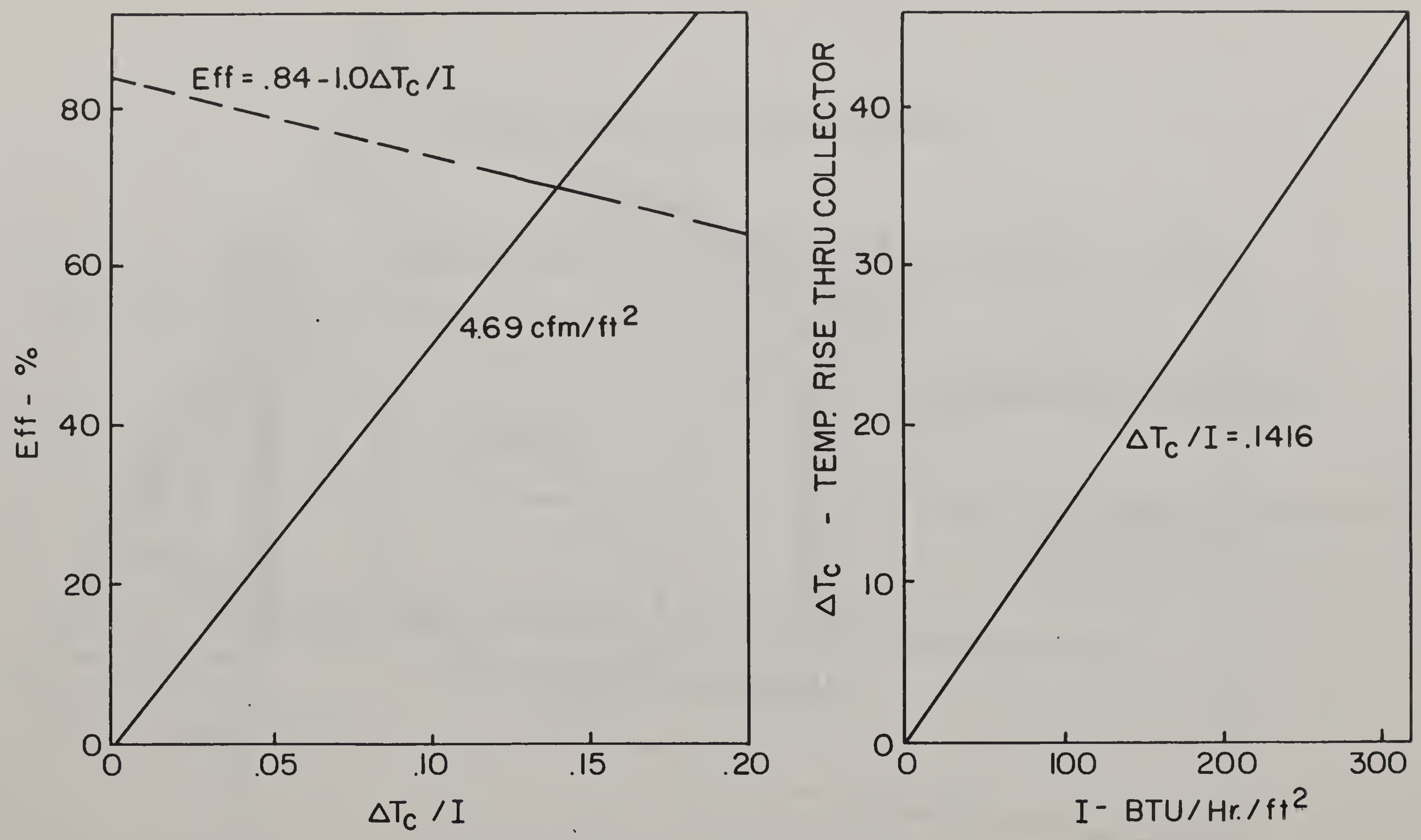
END VIEW-COLLECTOR CROSS-SECTION



AIR FLOW FOR COLLECTOR AND ROCK STORAGE



CLINE - FULL-DAY COLLECTOR PERFORMANCE



CLINE - FULL-DAY COLLECTOR PERFORMANCE

HOERR DEMONSTRATION

I. Louis Hoerr, Route 1, Taylor, MO, operates 1,500 acres of crop land divided between two locations 7 mi apart. The grain is sold as cash grain.

II. The objective of this demonstration is to illustrate use of a portable collector system to dry grain at two separate locations.

III. Two portable collectors, each 12 x 24 ft, were originally planned for this demonstration. Mr. Hoerr talked to commercial sales people and decided to use two collectors that were of metal construction. The collectors were purchased from Solar Search Corp., Cessna Park, IL. The first, Model "B", 8 x 24 ft is a covered plate collector. Vertically placed eliptical shaped metal air deflectors were placed on the absorber plate to generate air turbulence in the collector channel. The second collector is 8 x 28 ft. It is a suspended plate collector. The absorber plate is suspended, triangular in shape, with air flow on both sides. These two collectors were mounted on a trailer frame.

A 3/4 HP, 3,450 RPM, 12 in aeration fan is mounted on each collector. Air is forced through each collector and discharged into a common junction box. The heated air is conveyed from this box to the drying fans in a single canvas tube.

At one location the drying system consisted of a 35 ft dia. bin with two 10 HP centrifugal fans. Fifteen thousand bu of corn were dried with natural air and collector heat in 28 days. The first layer of 4,000 bu was loaded into the bin directly from the field at 30% moisture. Later layers were loaded hot from a high temperature continuous flow drier at 22% moisture. The savings of LP gas on 15,000 bu was $908.

At the second location the drying system was a 30 ft dia. bin and one 10 HP centrifugal fan. Ten thousand bu of corn were dried with an average of 18% moisture in 18 days. The savings in LP gas for 10,000 bu was $159. The total savings for the total 25,000 bu was $1,067.

IV. The cost of the two collectors was $6,697 for 416 sq ft of collector surface. This is a cost of $16.10/ft^2 of collector. An additional $1,101 was required for collector fans, wiring and controls.

V. The Model "B" collector had a 9 in dia. collar at the inlet and the outlet on the back of the collector. Very high static pressures were encountered with air flow rates normally used for grain drying. The highest air flow rate

obtained with a grain drying fan was 2.25 cfm/ft^2 at 1 in S.P. The restriction on air flow limits the amount of heat that can be collected for grain drying, although the efficiency of the collector at 1 cfm/ft^2 was quite acceptable.

The triangular plate collector did not have restrictions to air flows at the inlets or outlet. The performance of this collector was excellent. The data used to evaluate the two collectors was gathered over a 2 day period. Further data were not available because of a tape recorder malfunction.

The performance parameters of the collectors are listed below.

TABLE 1

Solar Search Collector Performance Data[1]

Model	$\Delta T_c/I$	All Day Efficiency (%)	Average Temp Rise (°F)
"B"	.255	28	54.0
Triangular Plate	.127	68	26.5

[1]Air flow:
Model "B" = 1.01 cfm/ft^2
Triangular plate = 4.95 cfm/ft^2
Av. Insol (I) = 210 BTU/hr/ft^2
ΔT_c (°F) = Collector Disc Temp - Ambient temp

VI. (Data and illustrations are shown on pages that follow.)

VII. The air flow through the Model "B" was 195 cfm while air flow through the triangular plate collector was 1,100 cfm. The Model "B" transferred an average of 11,290 BTU/hr. The other collector transferred an average of 31,990 BTU/hr. If the air flow rates had been equal, the difference in BTU/hr output between these collectors would have been expected to be about 10%.

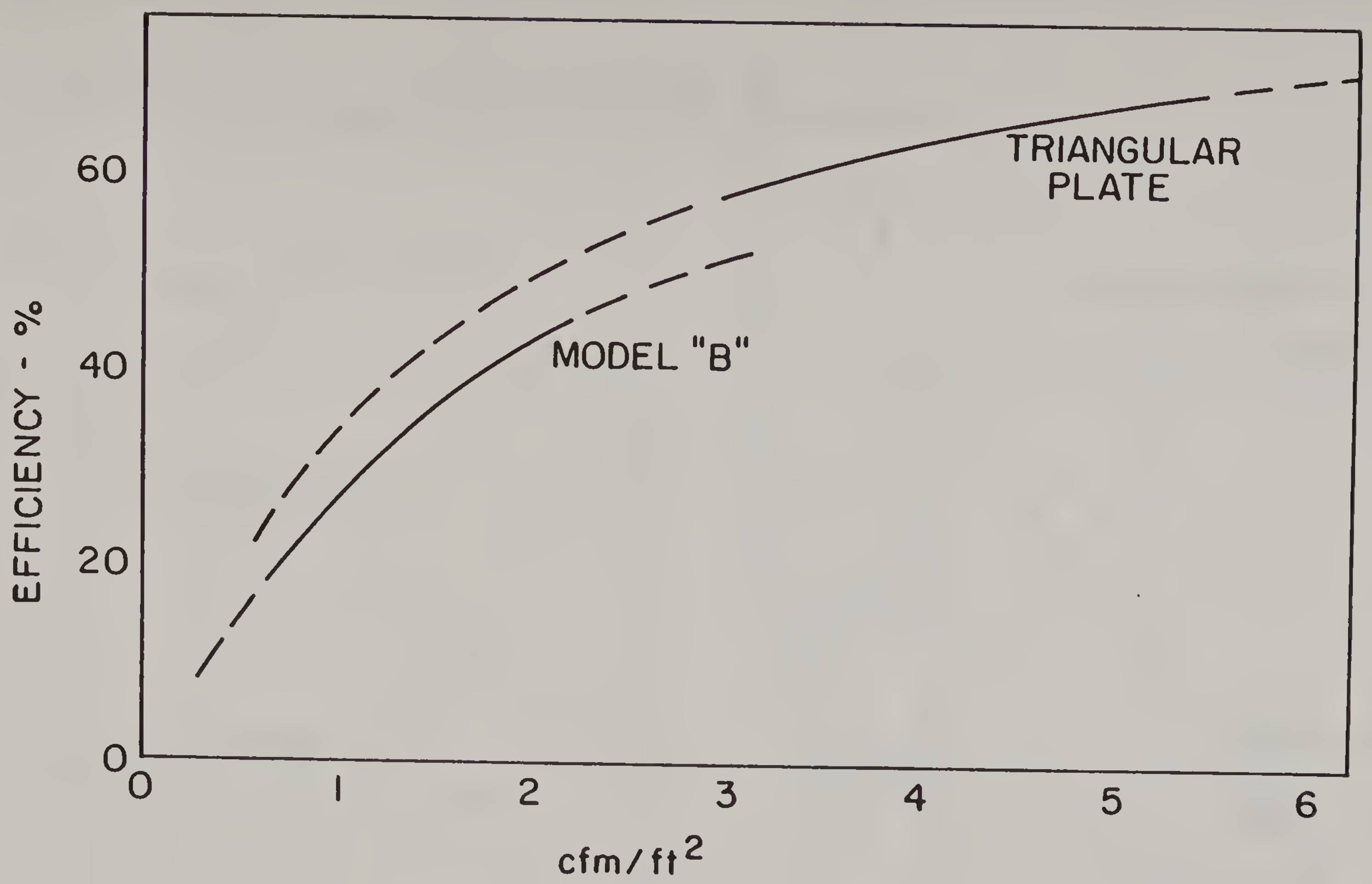
The payback for the collector system is based on a total investment of \$7,798. The savings accumulated this fall are \$1,067. The investment-savings ratio is:

$$\frac{7{,}798}{1{,}067} = 7.3$$

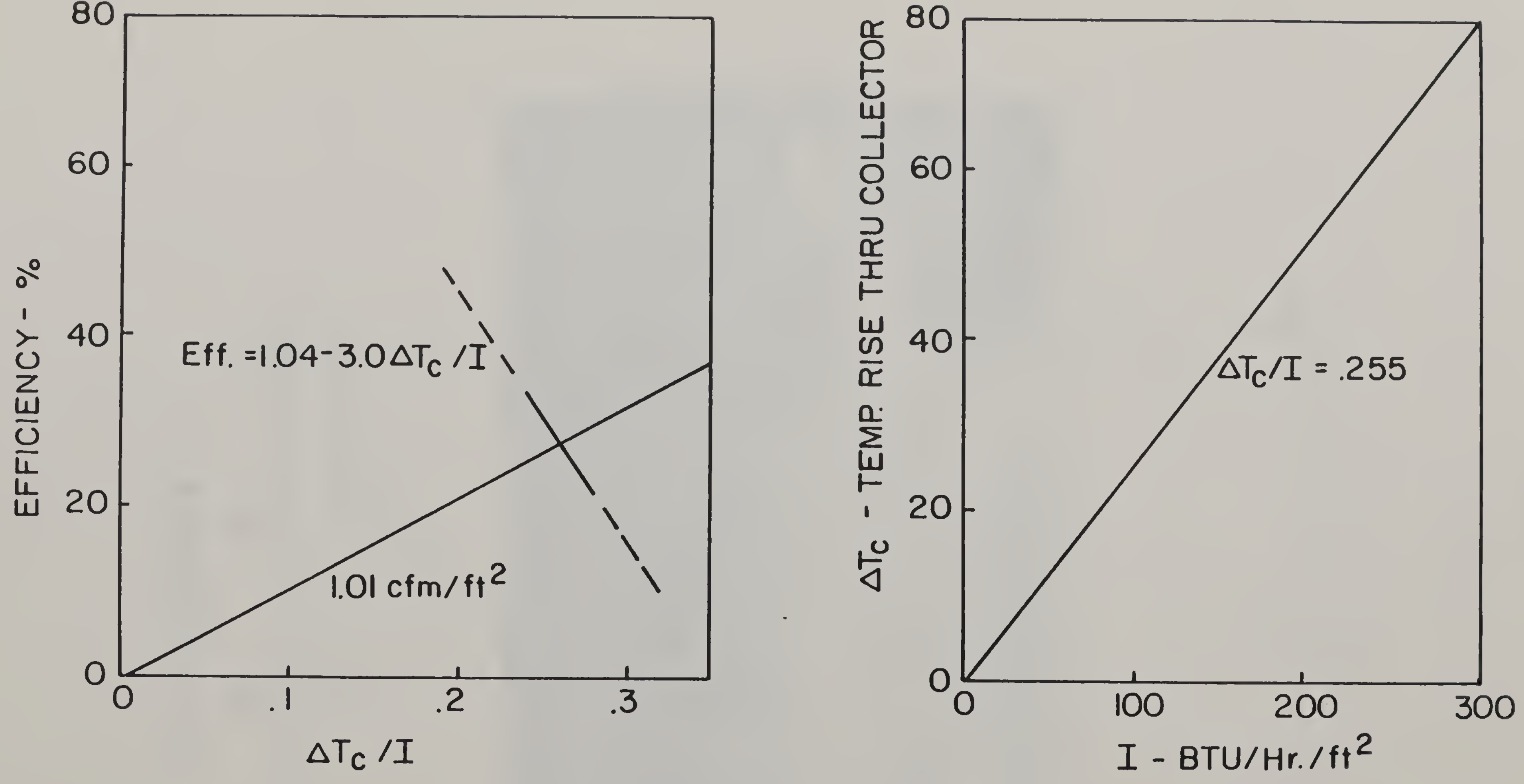
The payback assuming a 10% energy escalation rate is:

5.6 years based on 0% return on invested money;
8.0 years based on 10% return on invested money.

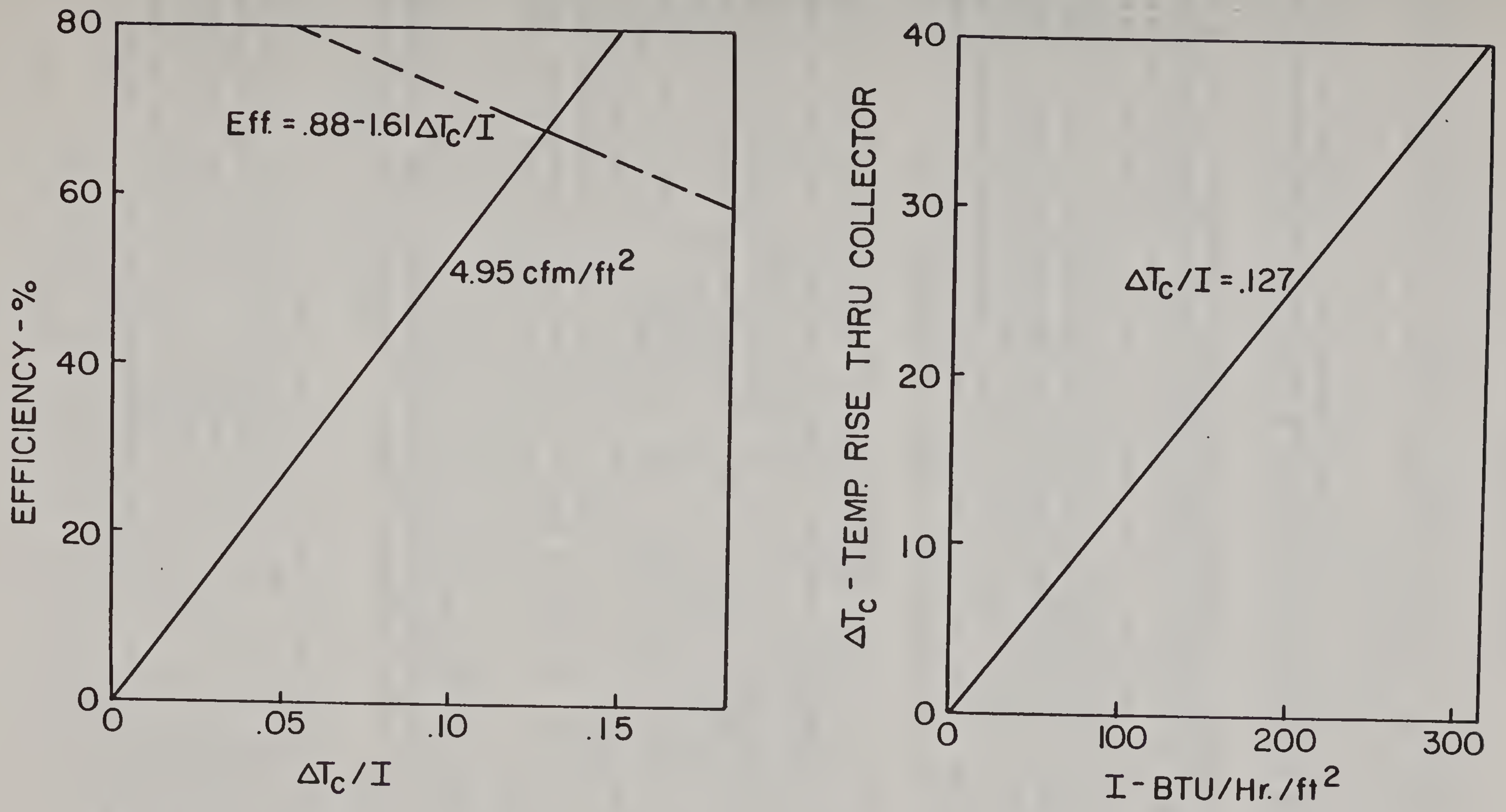
HOERR SOLAR COLLECTOR SYSTEM



HOERR - FULL-DAY COLLECTOR PERFORMANCE
SOLAR SEARCH MODELS



HOERR - FULL-DAY COLLECTOR PERFORMANCE
SOLAR SEARCH MODEL "B"



HOERR - FULL-DAY COLLECTOR PERFORMANCE
SOLAR SEARCH-TRIANGULAR PLATE

HARNESS DEMONSTRATION

I. John Harness, Jr. and Sons, Route 1, Montgomery City, MO, farm 1,200 acres of cropland. They also have a 45 sow farrow to finish operation.

II. The objective of this demonstration was to show how a solar energy collector system can be used for grain drying and for both shop heating and home heating.

III. Two commercial portable collectors were selected to provide the flexibility required for the multiple heating uses. One 8 x 20 ft unit was purchased from Sunduit and was of metal construction. The design was a suspended plate with the air flow under the absorber plate. The second collector was purchased from Solar Resources, Inc. This collector was of wood construction with double glass "thermopane" cover plates. The air flow was between the cover plate and absorber. The glass panels provided 126 ft^2 of operative area. The two collectors were operated during the winter of 1982 to help heat a shop and home.

The glass covered collector was expected to perform better than the other when low air flow rates and high temperature rises are needed. Therefore, this collector was connected to the house. The collector intake and discharge was attached to the house using insulated flexible ducts. The air return was taken from the area of a hallway, and the heated air from the collector was discharged into the cold air return of the furnace. The furnace blower operated continuously when solar heat was available. A 12 in. variable speed ventilation fan was mounted in the discharge duct of the collector. A differential thermostat control was used to turn the variable speed fan on when adequate air temperatures were available from the collector and off when they were not.

The Sunduit Collector was connected to the shop by replacing a storm window panel with plywood. The insulated flexible ducts were inserted through holes in the plywood into the shop.

The collectors were moved to the grain storage site for drying wheat and corn. The drying system consists of two 18 ft dia. bins and two 24 ft dia. bins. All bins are equipped with 7 1/2 HP fans with LP gas heaters. Flexible insulated ducts were used to convey heated air to the grain drying fans. The collector fans used were those furnished by the manufacturer. These air flow rates are low and it appears they were selected for heating applications.

The discharge and inlet openings on the Sunduit Collector were round collars on the back of the collector discharging directly into a 2 in. air channel. High pressure drops were encountered on this collector. The glass cover collector had a plenum box the entire length of the collector at the top and bottom for the inlet and discharge connection. Pressure drops were normal on this collector. The flexible tubing caused high pressure drops on both collector systems.

IV. The cost of the Sunduit Collector was $1,604 or $10.02/ft^2$. The total installed cost for two collectors was $7,356.07.

V. The fan on each of the collectors did not deliver the high air flow rates that are desirable for grain drying. The static pressure drops were high on both collectors because of collector pressure losses and/or flexible tube pressure losses.

The performance data are listed below:

TABLE 1

Full Day Collector Performance Data[1]

Model	cfm/ft^2	$\Delta T_c/I$	All Day Efficiency (%)	Average Temp Rise (°F)
Sunduit B	1.62	.17	29.2	35.7
Solar Resources	1.80	.17	32.5	35.7

[1]Av. Insol (I) = 210 BTU/hr/ft^2
ΔT_c (°F) = collector disc temp - ambient temp

The bushels of shelled corn dried in 1982 are listed below. Drying was accomplished with solar energy only. No LP gas was used.

Bu	Initial Moisture (%)
1,500	24.7
900	30.0
1,740	30.0
600	21.0
4,740	26.4 (Average)

The farm records show that in past years he used 474 gal of LP gas per year at a cost of $331.80.

There were continuous data-logger problems in recording the shop and house heating data. Mice cut wires and other problems resulted in data losses. Data were collected to evaluate collector performances.

VI. (Data and illustrations are shown on pages that follow.)

VII. Six hundred gal of fuel oil were used to heat the farm home. The collector system was estimated to have furnished 4.8 million BTU. With the furnace efficiency estimated at 30%, the collector furnished 16.8% of the home heating. This amounted to a savings of $100.69.

The shop was equipped with a wood burning stove. The operators built fires on occasions when they knew they would work throughout the day. Many times for short time jobs they would not build a fire. The shop collector came on and operated if sunlight were available. Since heat was always available in the shop, the operators found that they would do many more jobs than they would have with the wood stove heat alone. It is difficult to put a dollar value on this kind of use.

The payback is:

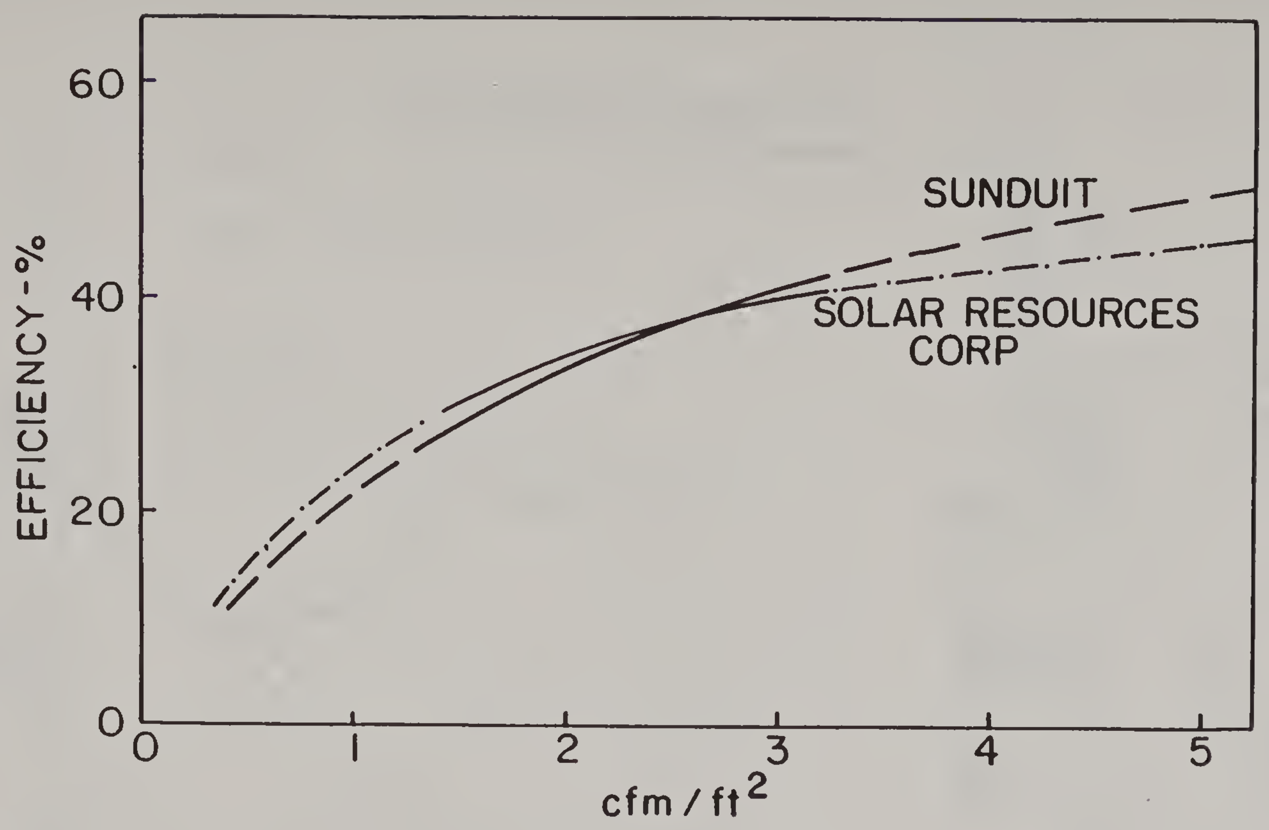
Total investment was \$7,356.07 and savings at \$432.49

$$\frac{\text{Investment}}{\text{Savings}} = \frac{7,356.07}{432.49} = 17.0$$

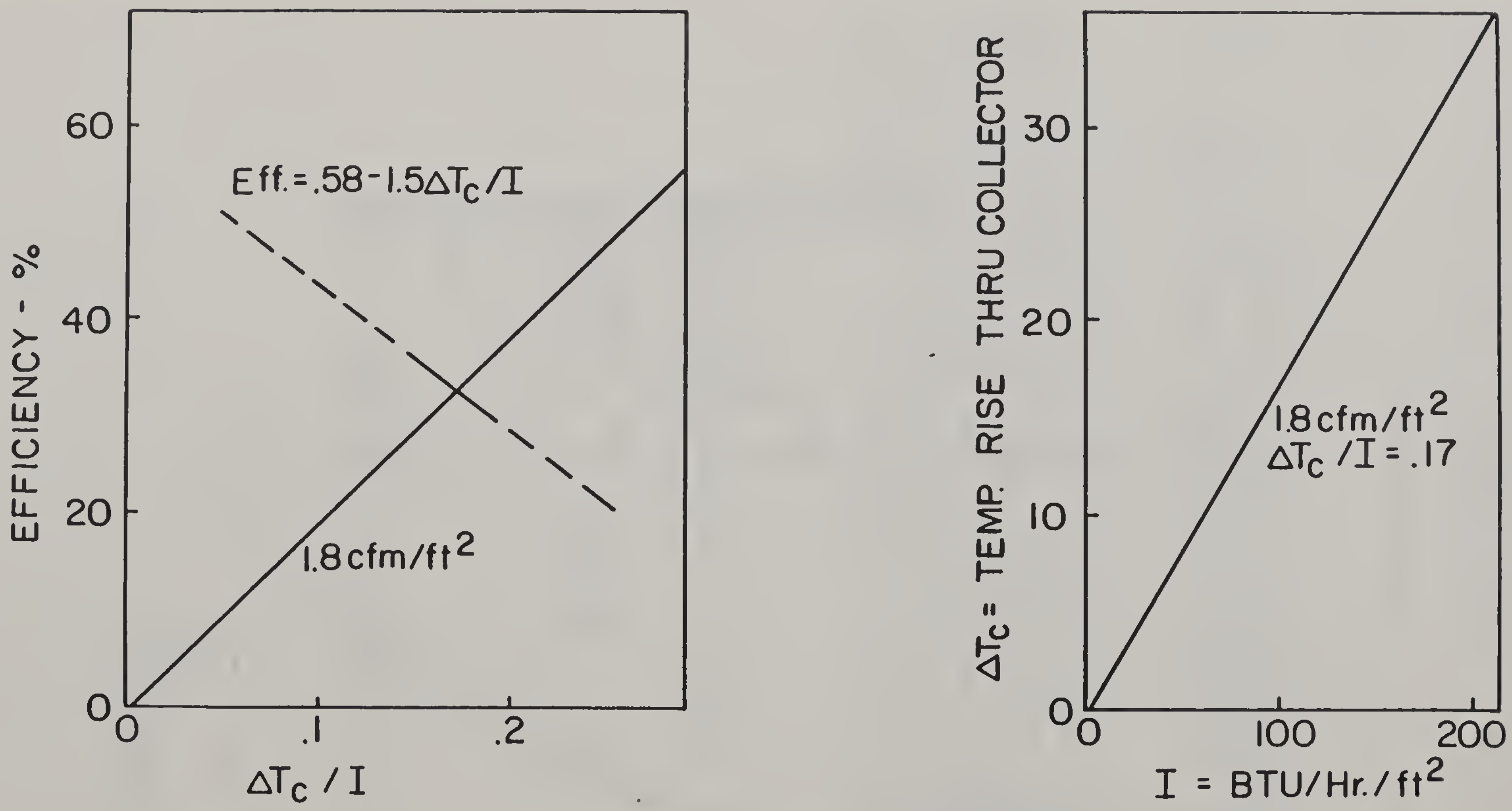
The energy escalation rate is 10%:

<u>Years</u>

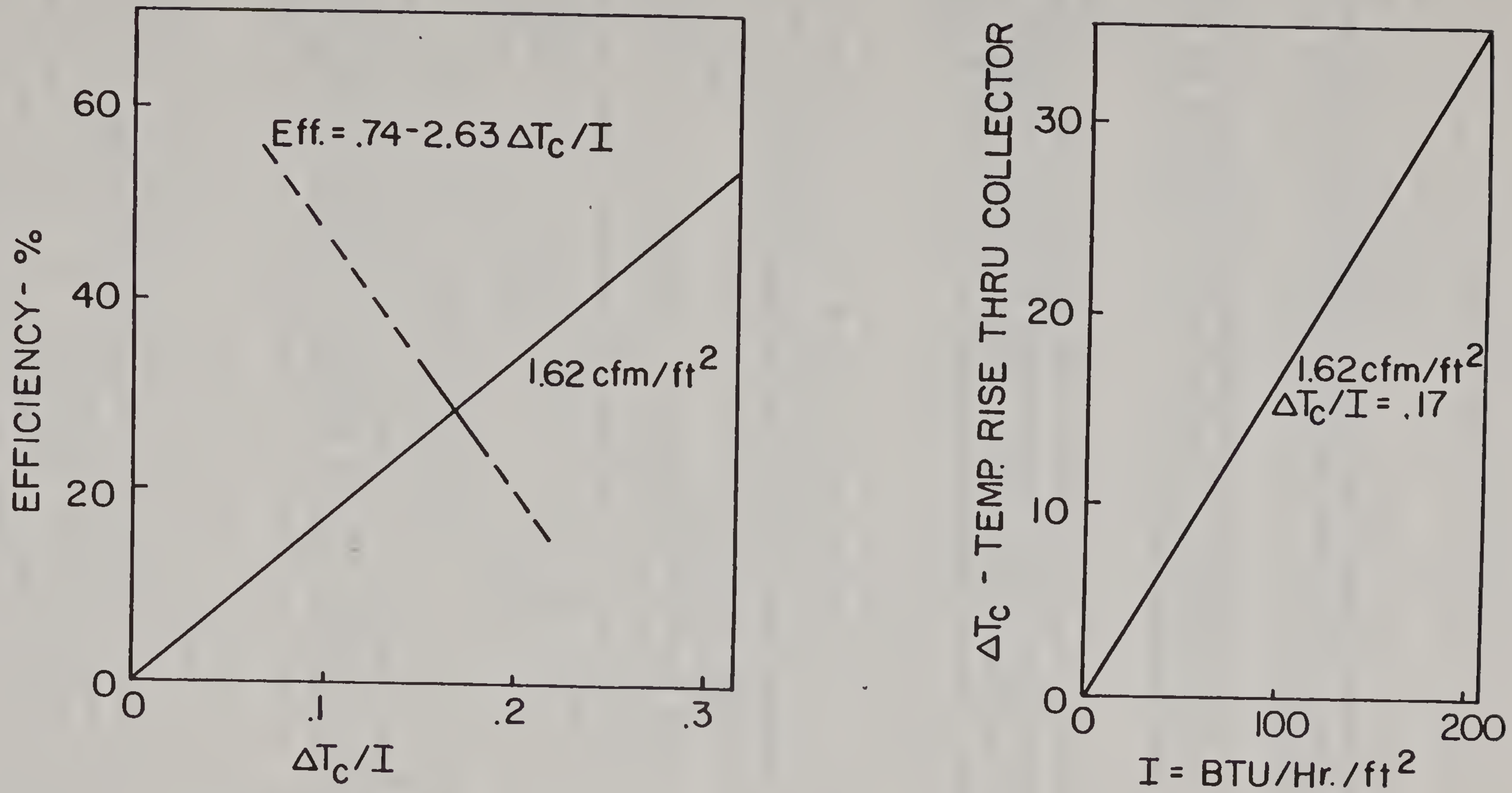
10.5 assuming a 0% return on invested money;
20.0 assuming a 10% return on invested money.



HARNESS - FULL-DAY COLLECTOR PERFORMANCE



HARNESS - FULL-DAY COLLECTOR PERFORMANCE DATA
SOLAR RESOURCES CORPORATION



HARNESS - FULL-DAY COLLECTOR PERFORMANCE
SUNDUIT MODEL "B"

CLARK DEMONSTRATION

I. Everett Clark, Jr., Route 1, Montgomery City, MO, operates a 450 acre farm. Grain production includes corn, wheat and soybeans. Livestock includes 25 sows in a farrow to finish operation.

II. The objective of the demonstration was to illustrate the use of a solar collector system to furnish heat for both grain drying and shop heating.

III. The solar collector system consists of two collectors, each 12 x 24 ft. The collector design is a modified suspended plate design. A selective paint was used on the absorber plate of the collector, with a brown paint used on the back side. The collectors are oriented in line with space between them for an air plenum. Air flow through the collector is horizontal.

When grain is being dried, heated air is pulled through the collectors to the plenum by a 24 in fan and discharged to the grain drying fans in a canvas tube. In this case air flows on both sides of the absorber plate.

The air flow in the collectors is partitioned when the heated air is used in the shop. The collector plenum is partitioned horizontally and an 18 in dia. fan forces air through the top half of each collector to a crossover duct at the end of each collector. The air is returned in the lower half of each collector in a closed circuit fashion.

The evaporation coils of a 2.5 T heat pump are located in the lower part of the collector plenum. The refrigerant, having picked up heat from the air, passes through lines that are insulated and buried and run to the shop which is located 150 ft from the grain storage and collector system. The condenser coils, located in the shop, furnish heat for that building.

Controls are used to open an air discharge shutter on the top plenum and also an air inlet valve on the bottom plenum. This control operates on a temperature rise above $55^{\circ}F$ in the plenum to allow outside air to the heat pump when the solar heated air temperature is above the required limits for the heat pump. A second set of controls will allow use of outside air under conditions where the temperature in the closed collector system is below outside temperature.

The closed circuit concept should minimize defrost cycles. It should allow the heat pump to operate with a 40°F temperature rise above outside temperature when solar energy is available.

The storage and drying system consists of two new 24 ft dia. bins with 10 HP drying fans. Two older 21 ft dia. bins were improved by adding drying floors and drying fans.

IV. The collector system is completed at a cost of $3,500. This is a cost of $6.07/ft^2. The heat pump installation is not completed, but completed costs are expected to be $2,800.

V. Full-day performance of this collector system is not available. Short time performance for two different air flow rates is available. The construction is similar to the Cline system and therefore all-day performance should be the same.

The tested collector performance data are listed below:

Instantaneous Collector Performance Data[1]

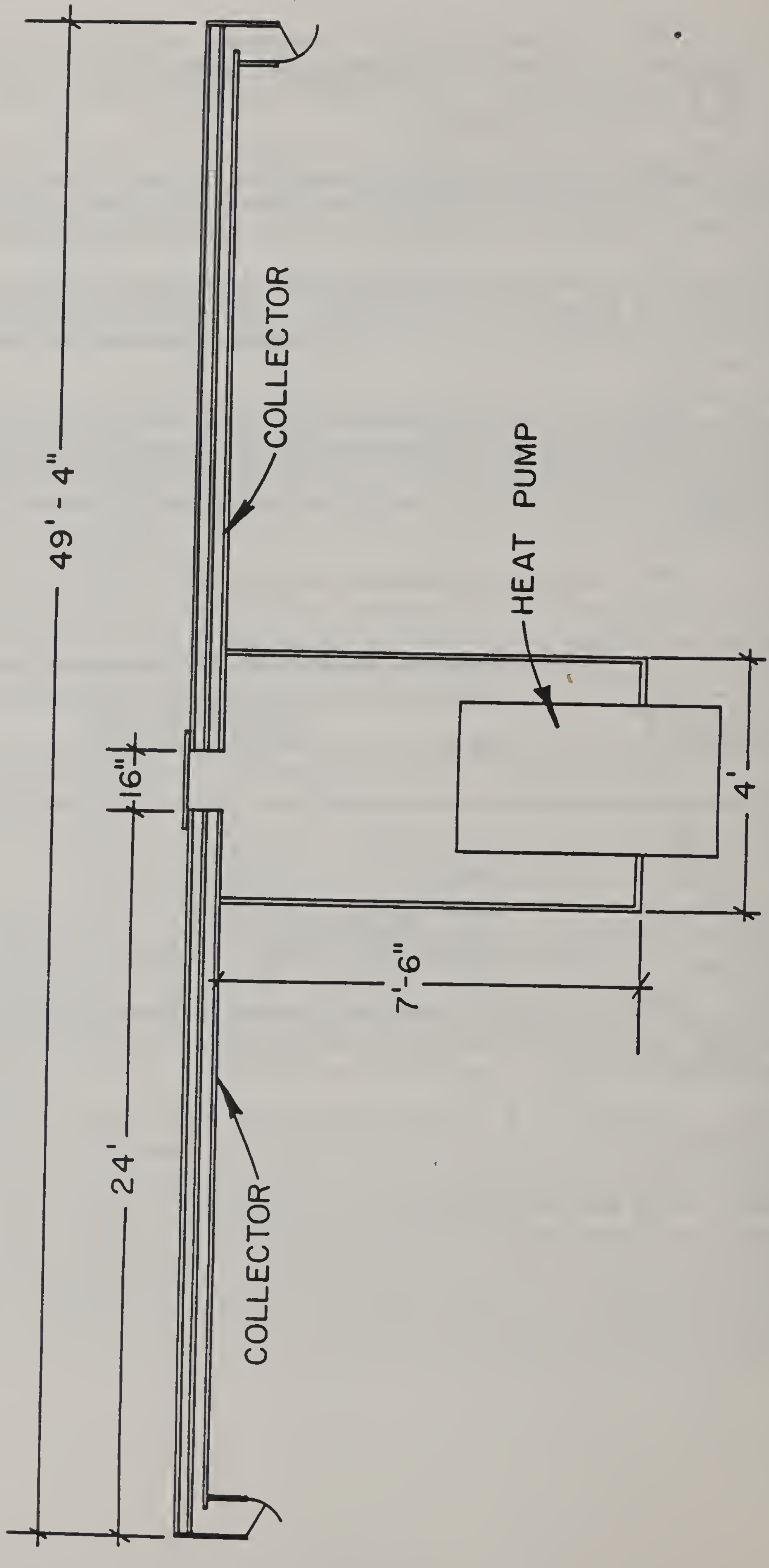
Air flow cfm/ft^2	$\Delta T_c/I$	Instantaneous Efficiency (%)	Average Temp Rise (°F)
5.22	.121	67	25.4
7.08	.094	70.3	19.7

[1] Av. Insol (I) = 210 BTU/hr/ft^2
ΔT_c (°F) = collector disc temp - ambient temp

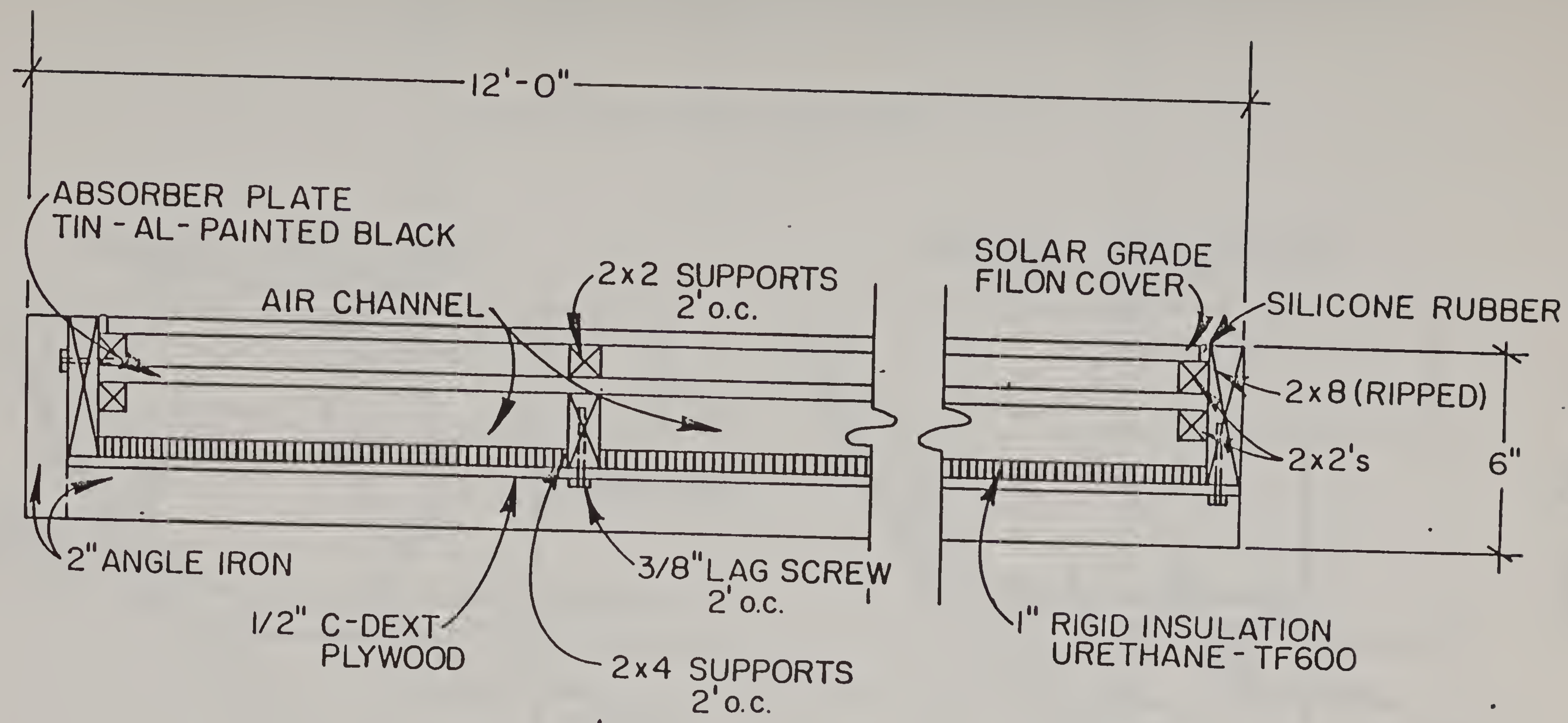
Kal-lite was used as a cover plate on this collector. A value of 0.899 transmittance was measured on this collector.

VI. (Data and illustrations are shown on pages that follow.)

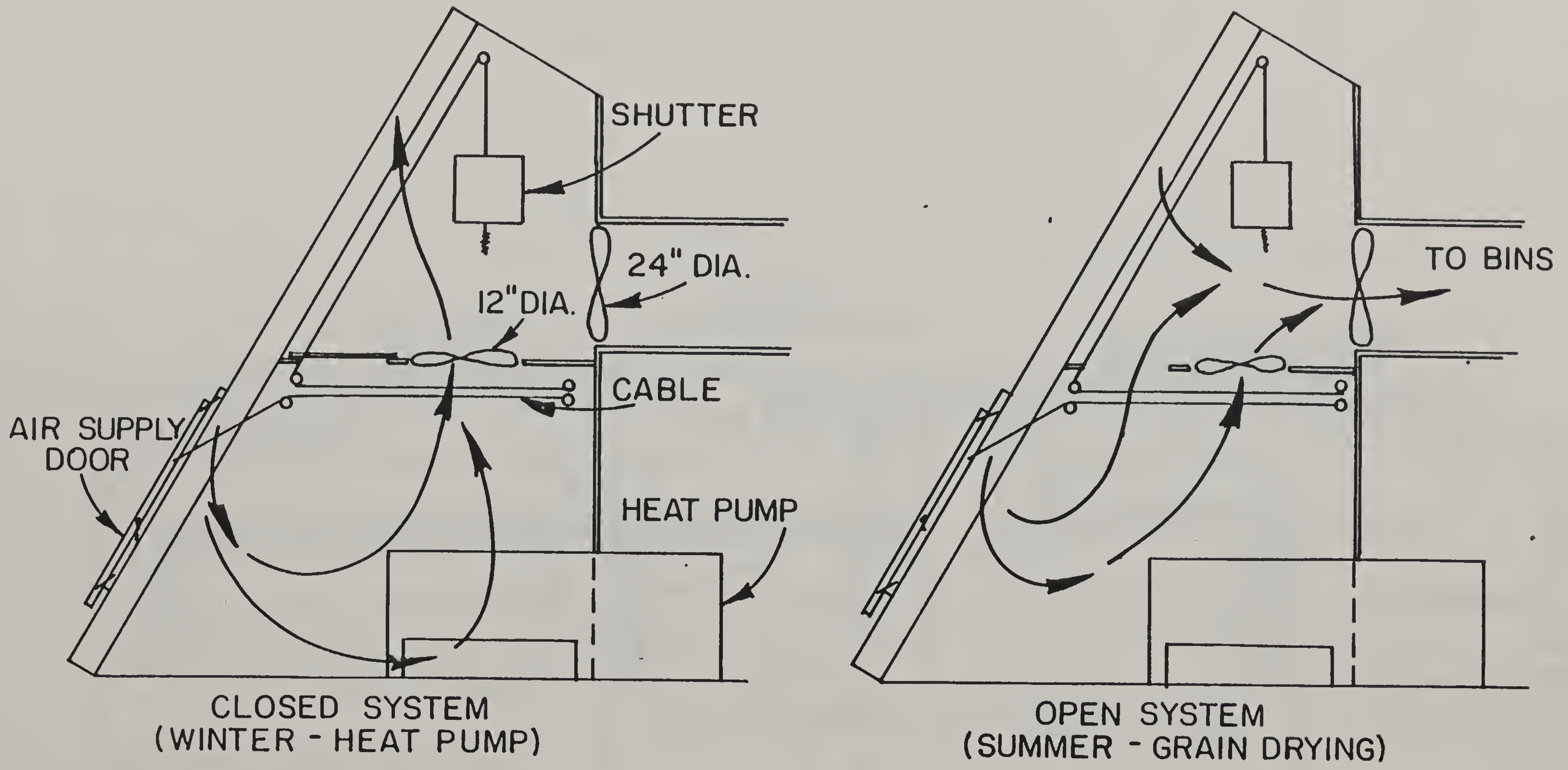
VII. No data available.



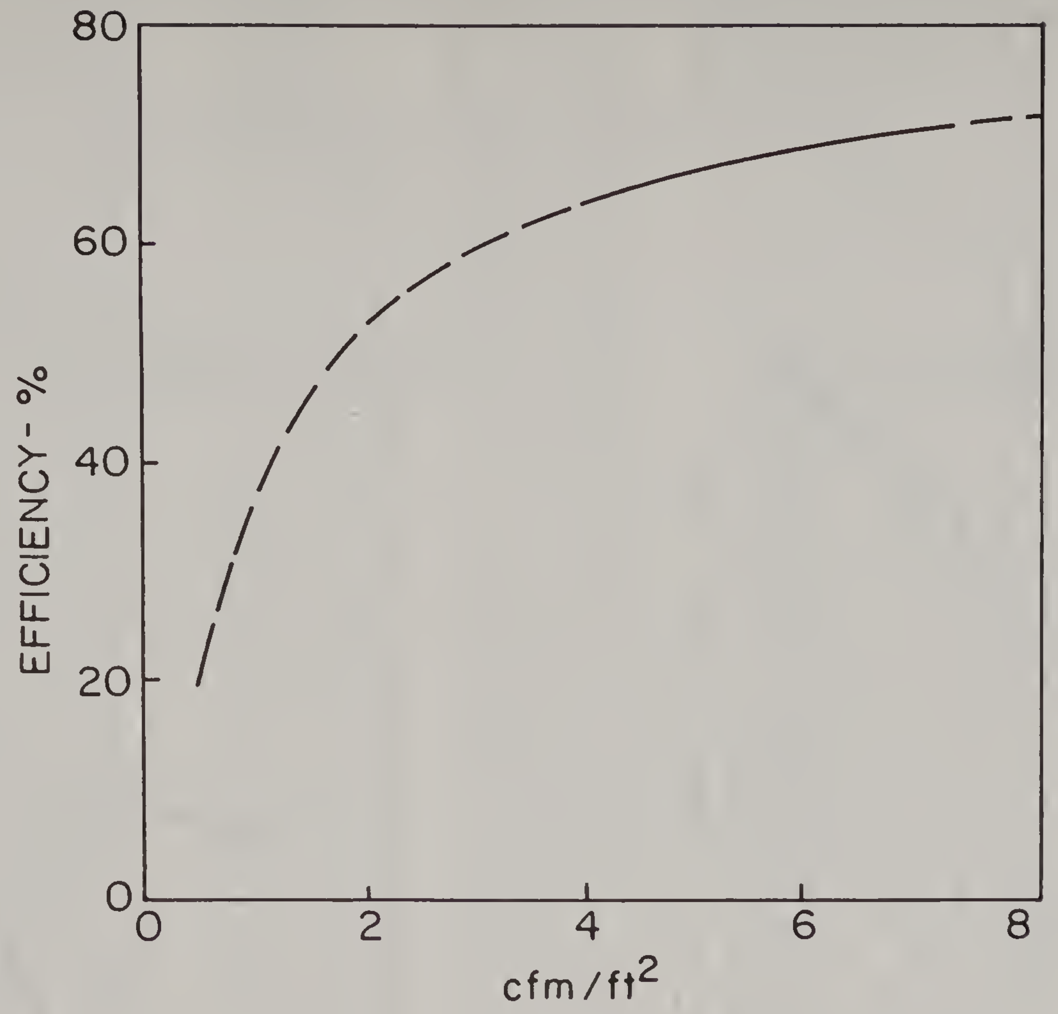
TOP VIEW OF COLLECTOR



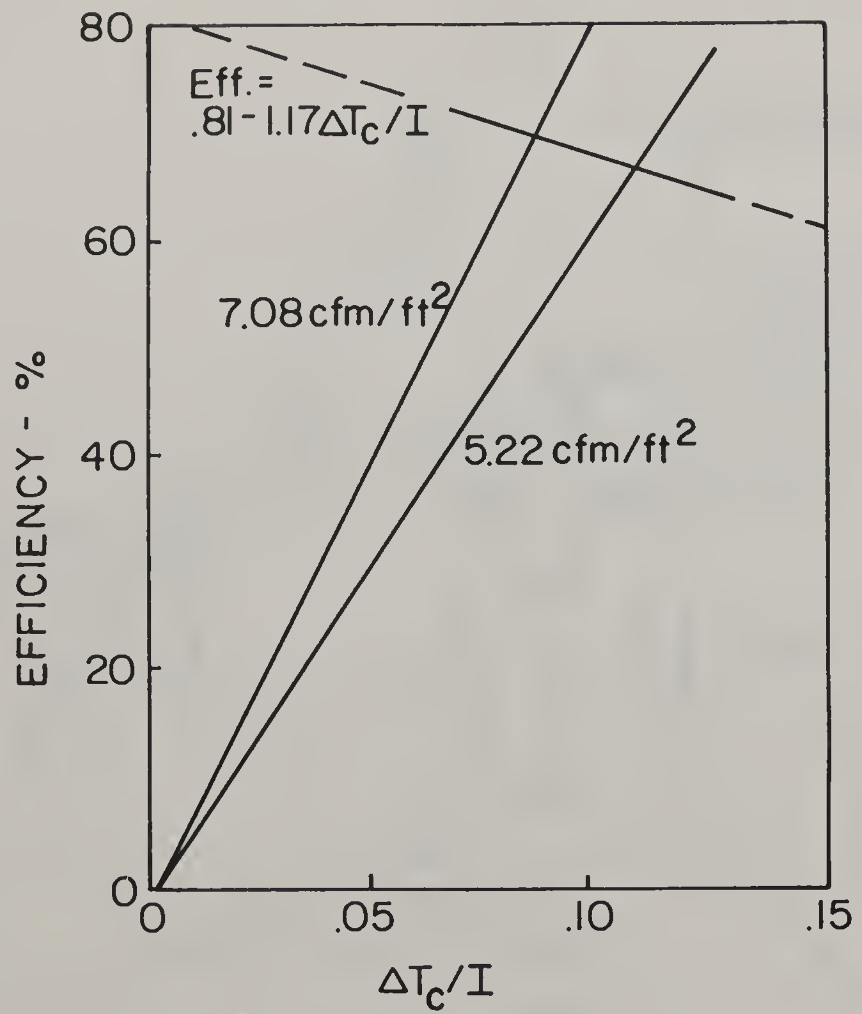
END VIEW-COLLECTOR CROSS-SECTION

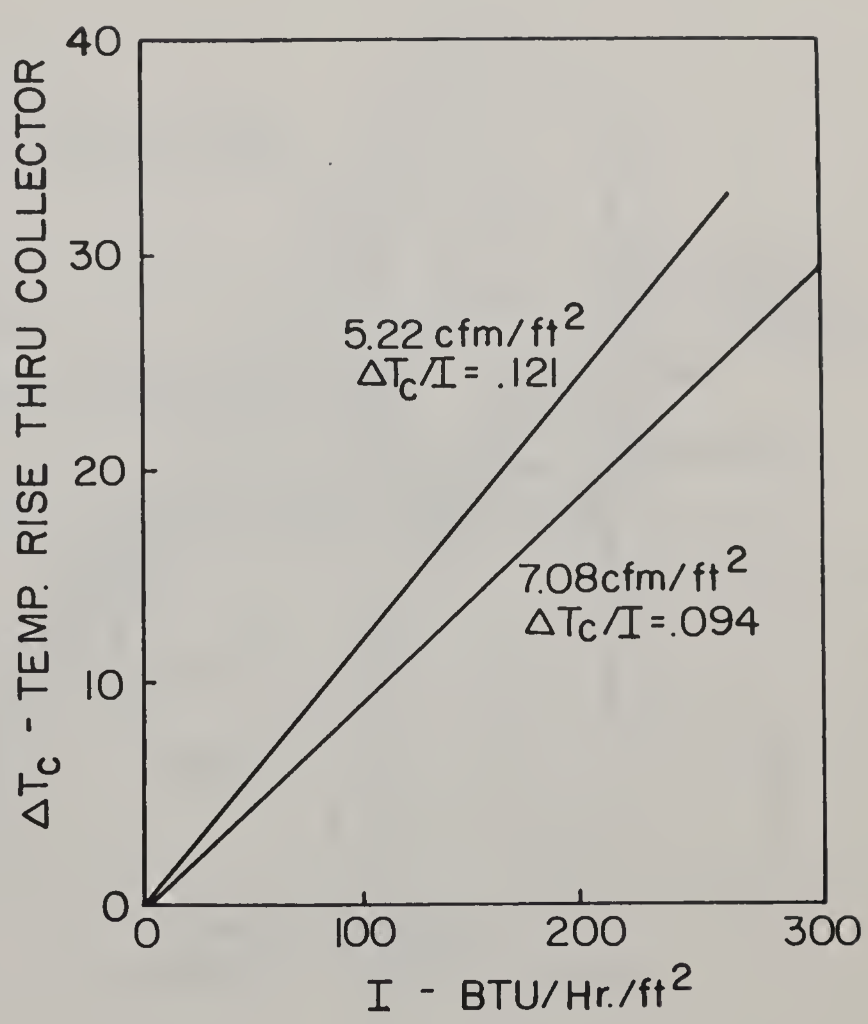


AIR FLOW FOR DRYING AND HEATING



CLARK COLLECTOR TEST DATA - SELECTIVE PAINT





CLARK COLLECTOR TEST DATA - SELECTIVE PAINT

TIEMEYER DEMONSTRATION

I. Paul H. Tiemeyer, Rural Route, Rock Port, MO, operates 1,500 acres of cropland. Grain is dried and stored on the farm and sold as cash grain.

II. The objective of this project was to demonstrate how the roof of an ear corn crib adjacent to the drying and storage facility could be converted to a dual use solar collector. In addition to drying grain, the collected energy is used for heating a shop.

III. The south roof of the corn crib provided room for 840 sq ft of collector area. A suspended plate collector design with air under the absorber plate allowed simple retrofit construction. The metal roof was painted with selective black paint and then a filon corrugated cover plate was attached to 2 in x 2 in boards nailed to the roof. The inside of the rafters were covered, thus providing air flow channels. Batt insulation was fitted inside the air channel for insulation value and to reduce the excessive channel depths.

Air for drying enters the collector channels at the ridge from inside the building. The heated air is collected in a duct at the eave of the building inside a lean-to shed. A fan at the end of the collection duct forces the heated air through ducts and canvas tubes to drying fans at eight grain storage bins.

A high temperature continuous flow (Circu-Flo) dryer is installed in one of the bins. A 15 HP vane axial fan is attached to this 27 ft dia. bin. Grain is discharged from the dryer at 18-19% moisture while it is still warm, and conveyed to storage where drying is completed.

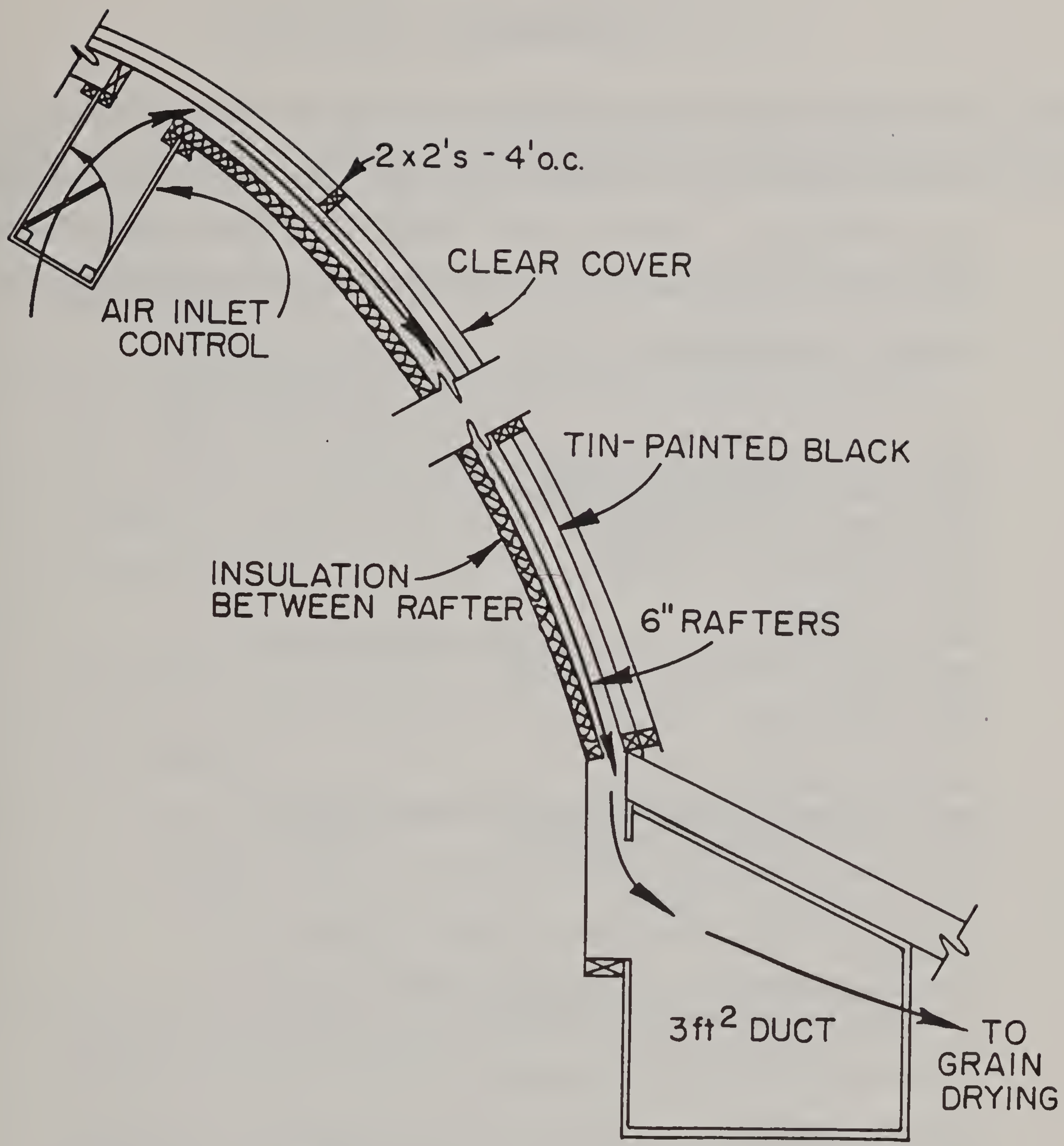
A heat pump is planned for use with the collector system when the shop is being heated. For use with the heat pump, the collector duct is partitioned at its mid-point, and air is bypassed through a separate plenum containing the evaporator coils of the heat pump. The duct to the drying system is closed, and the fan is used to force air past the evaporator coils and up one half of the collector. The air is discharged into a crossover duct at the ridge and is returned to the fan on the opposite half of the collector. Controls and provisions are provided to access outside air when the collector generates temperatures too high for the heat pump. Provisions are made to vent outside air into the system when the heat pump reduces the solar heated air temperature below outside air temperature. The refrigerant lines are insulated and buried between the collector and shop and carry the refrigerant to the condenser coils in the shop. The shop is located 150 ft from the collector.

IV. The costs of the collector system and ducts for grain drying are $6,900. This is a cost of $8.21/$ft^2$.

V. This system is under construction and not completed for any test data. The design is similar to the Gerber collector, and it is expected that the performance would be the same.

VI. (Data and illustrations are shown on pages that follow.)

VII. The problem of distribution of solar heat to the points of use has been a concern on each of these demonstrations. This farm is the most complex and costly.



COLLECTOR CROSS-SECTION

APPENDIX A

The following University of Missouri Area Extension staff members were heavily involved with this project from its inception. Without their individual and collective help, there would have been no solar grain drying demonstration project in Missouri.

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Jean Gatzmeyer
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Montgomery City, MO 63361

APPENDIX B

ROCK HEAT STORAGE DESIGN

The following procedure can be used to determine the size, shape, air flow rates and rock size for efficient heat storage in crushed limestone rock.

1. Determine the following data from the performance of collector.

   a. Collector CFM - determined by required minimum ventilation rate.
   b. Total BTU to be stored.
   c. Average temperature rise through collector.

2. Assume an effective rock diameter (1/2 - 2").

3. Calculate total ft^3 rock required (V_r) to store heat.

$$V_r\ (ft^3) = \frac{\text{BTU Stored}}{C_r \times \#/ft^3 \times \Delta T}$$

Where:

C_r = specific heat of rock (assume 0.2)

$$\#/ft^3 = \left[1 - .5(\text{Dia"})^{.0807}\right] \times 150$$

ΔT = Average temperature rise through collector

4. Determine shape of storage - assume rock diameter.

$CFM/ft^2 = 10.05\ (\text{Dia"})^{.5438}$
(Max. air flow for rock diameter)

$$\text{Area of Rock Face} = \frac{CFM}{CFM/ft^2}$$

$\text{Length} = .4853\ (CFM/ft^2)^{1.162}$
(Min. length for air flow for 95% of heat storage)

Calculate volume of rock and compare V_r in 3.

5. Calculate static pressure required.

$$S.P.\ (in/ft) = \frac{.0002}{\text{Dia"}} \left[\frac{CFM}{ft^2}\right]^{1.537}$$

6. Evaluate design and repeat if necessary.

APPENDIX C

Analyzing Field Test Data for Solar Collectors

The following procedure was developed to analyze collector performance.

1. Plot insolation (I) vs. air temperature rise through the collector (ΔT_C). The slope of this line is $\Delta T_C/I$.

2. Calculate efficiency using the following formula.

   $$\text{Eff} = \text{cfm/ft}^2 \times (\Delta T_C/I)(1.191 - .00176\ R)$$

   Eff = Percent efficiency

   R = Air temperature entering collector fan, $^{\circ}F$

   ΔT_C = Collector disc temperature - ambient, $^{\circ}F$

   I = Insolation, btu/hr/ft^2

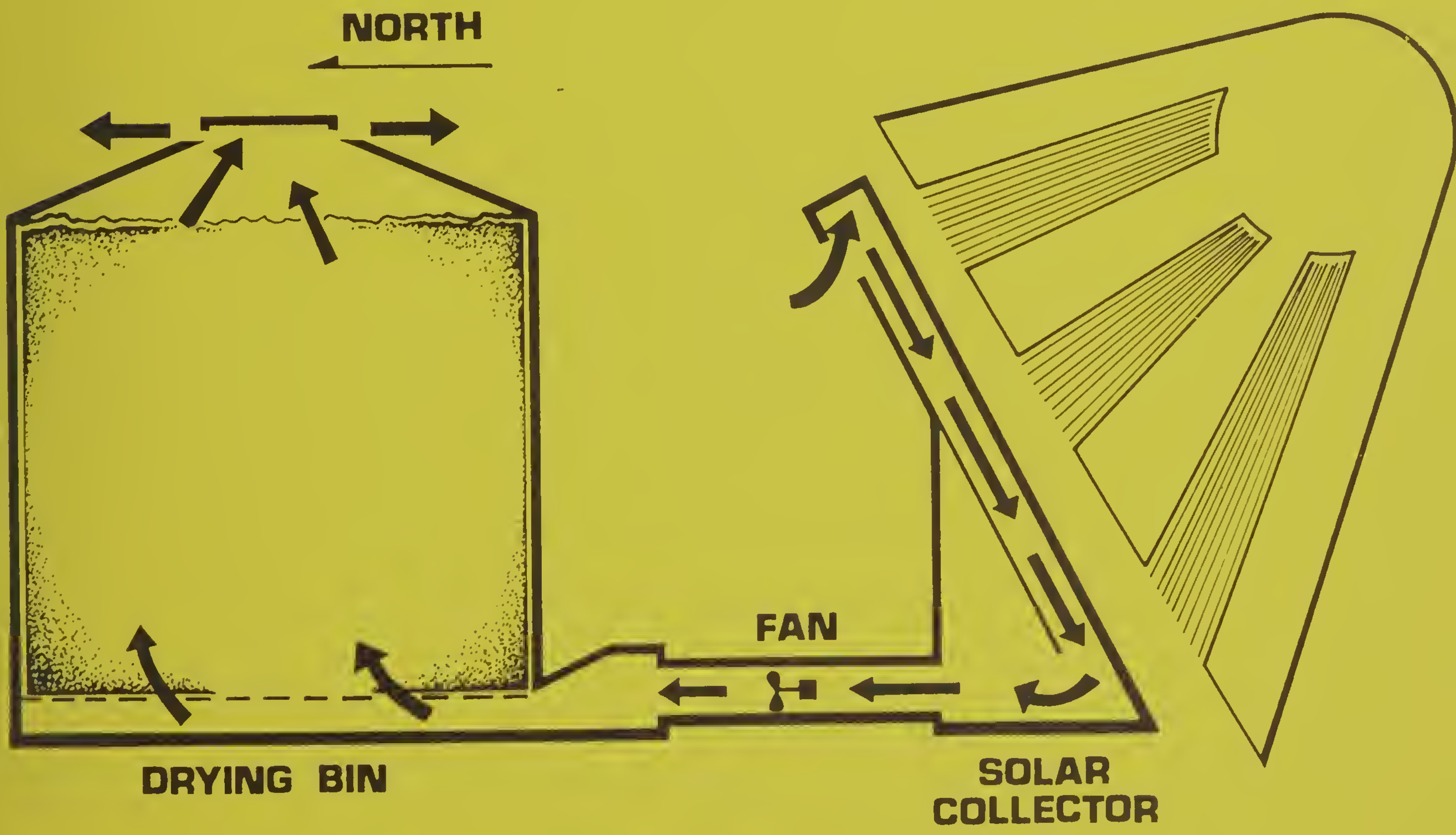
3. Plot $\Delta T_C/I$ vs. Efficiency for two or more values of air flow and draw a line through the points (a particular air flow rate will plot as a straight line that radiates from the origin).

4. The line plotted in step 3 represents the performance of the collector. The slope Eff/ΔT_C is the loss factor of the collector and can be used to show the loss in efficiency from the theoretically possible efficiency (approaching infinite air flow with associated infinitely small temperature rise). The following formula is used.

   $$\text{Eff} = \text{Intercept} - (\text{slope})\ (\Delta T_C/I)$$

ON-FARM SOLAR GRAIN DRYING

DEMONSTRATION PROJECT



CLEMSON UNIVERSITY COOPERATIVE EXTENSION SERVICE
Clemson, South Carolina

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FINAL REPORT

of

ON-FARM SOLAR GRAIN DRYING

by

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Project Engineer

and

R. A. Spray
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December 31, 1982

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SOLAR GRAIN DRYING FINAL REPORT

INTRODUCTION

Solar grain drying in South Carolina and in the southeastern U.S. seems at first to be a natural. Some restrictions, however, that are not readily apparent are early corn harvest beginning in late July, annual rainfall of 50 to 60 inches per year, and over-wintering of destructive storage pests. Early harvest is by far the highest deterrent to solar drying. With harvest temperatures in the 90's the drying time available has to be reduced if spoilage is prevented. Estimates based on weather data indicates that corn would spoil about 75 percent of the time when dried with no supplemental heat and starting moisture content above 22 percent wet basis.

Nine solar on-farm drying systems were designed and installed as part of the USDA-DOE demonstration project. These systems were built on a cost-sharing basis between the farmer and the Cooperative Extension Service of Clemson University. Agricultural engineers designed and helped construct these projects over the time period 1981-82. The project was planned for an additional year but was terminated by U.S. DOE as part of their departmental phase out. Most of our systems are operational but limited testing has been done. Monitoring and data acquisition will be continued as time and funds are available locally.

The main goal of the project was to determine the feasibility of solar drying. Determination of the economics, construction techniques, design concepts,materials selection, and multiple use concepts of solar applications to on-farm drying were to be investigated.

Preliminary designs developed for the project proposal indicated that the only solar system that would be competitive with alternate fuels was a system of simple design incorporating straight forward construction techniques so that farm labor could construct them out of readily available materials. These criteria provide a challenge for the designer. Work by other extension engineers here at Clemson indicated that a value of 800 Btu/square foot - day was a realistic design value for sizing simple air type collectors. Peak heat collection on clear hot days would reach nearly three times this design value. These problems of over drying were anticipated.

Solar drying offers alternate operational schemes for the farmer when seasonal demand, emergencies and political decisions cause shortages of alternate fuels.

Proposed solar designs for retroffiting on to existing farm systems are classified as either portable or permanent. Solar panels and related duct work large enough to provide meaningful drying are not easily or readily portable. Size and ease of mobility may restrict multiple use collectors.

The primary solar panel designs used here in South Carolina are based on the collectors developed at Purdue University and the University of Illinois. Airflow rates and other operational parameters were modified to South Carolina conditions. A more definitive operational analysis will be completed over the next two years.

DEMONSTRATION FARMS

Rufus Cribb

Rufus Cribb is a large row crop farmer located on U.S. 601 in Hampton County. This 1,800 acre farm in the southern part of South Carolina grows corn, soybeans and wheat. Most of the wheat and soybeans are produced for certified seed. Mr. Cribb uses center pivot irrigation systems on about 1,000 acres of crops.

High moisture grain is first dried in a Shivvers continuous flow in-bin dryer. This dryer consists of a 30 foot diameter bin equipped with two 18.5 Hp fans. Grain is fed into four 24 foot diameter bins having total storage capacity of 20,000 bushels by an overhead auger. Air is supplied to each set of bins by a 7.5 Hp aeration fan. (See Appendix Fig. A-2.)

Goals

In order to obtain maximum utilization the following objectives were used to design and construct this solar collecting system:

* Provide solar assisted drying of corn with a moisture content below 20%.
* When needed, solar heated air will be used to dry soybeans and small grains.

System Description

This solar drying system consists of two 12' by 16' portable collectors designed by the University of Purdue. (See Appendix Figure A-1.) This basic design has a 3.5 inch deep air channel between a plywood back plate and the absorber plate. Another 3.5 inch deep air channel, between the absorber and a transparent cover plate, allows air to enter the collectors through a cross-sectional area of 7 square feet. Air enters the solar collecting system from each end and is drawn through to a plenum section created when the two collectors are joined. Solar radiation is absorbed by a black, sheet metal absorber plate. Heat is picked up by passing ambient air over the 384 square feet of absorber plate.

The solar collecting system is connected to a 7.5 Hp aeration fan by a series of 18" diameter flexible ducts. These ducts are attached to a square plywood doghouse that encloses the fan. The fan creates the suction force needed to draw air through the solar collectors. A damper, attached to the plywood doghouse, allows outside air to enter the grain bin when aeration is needed.

High moisture corn is first dried by the Shivvers dryer to a moisture content of approximately 20%. The grain is then placed in a storage bin where solar heated air finishes the drying process. Soybeans and wheat will rely totally on solar heated air for drying.

Cost

The total cost breakdown is divided into two categories:

1)	Solar Dryer	$1,872.04
2)	Air Duct System	225.00

With a total of $2,097.04 an average of $5.46 was spent per square foot of collector.

Construction and Operating Suggestions

* Completely seal the solar collecting system against air leaks. An air tight system has a high performance.
* Firmly anchor the portable collector to the ground.
* Keep collector surface free of debris. Debris buildup will decrease solar transmittance thus decreasing performance.
* Preserve all wood building materials by painting with an oil base paint.

Suggested Modifications

From our experience with the University of Purdue design, the following suggestions are given to modify this solar system:

* Locate solar dryers as close to the grain bins as possible. This will minimize the cost of the duct system.
* When connecting the duct system to the fan, allow for a damper to let outside air to pass through the grain bin. This will enable aeration when needed.

<u>Francis Kearse Farm</u>

Francis Kearse owns a farm approximately 19 miles southeast of Bamberg, the county seat. This 600 acre row crop operation serves as a home base for a seed and fertilizer distributorship as well as a farrow-to-finish hog operation. His crop rotation consists of soybeans behind wheat and oats, and corn.

He has an on-farm handling and storage facility consisting of seven bins ranging in size from 5,000 to 7,000 bushels all of which are arranged in a horseshoe shape. A concrete pit, located in the center of the horseshoe, serves as both a dump and loading pit. Portable augers facilitate the handling of grain into and out of the storage bins. A wet holding bin feeds a Butler continuous flow dryer to complete his facility. (See Figure A-3).

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Goals

In order to obtain maximum utilization, the following objectives were used to design and construct this solar collecting system:

* Provide solar assisted drying of corn with a moisture content below 20%.
* When needed, solar heated air will be used to dry soybeans and small grains.

System Description

This solar drying system consists of two 12' by 16' portable collectors designed by the University of Purdue. (See Appendix Figure A-1.) This basic design has a 3.5 inch deep air channel between a plywood back plate and the absorber plate. Another 3.5" deep air channel, between the absorber and a transparent cover plate, allows air to enter the collectors through a cross-sectional area of 7 square feet. Air enters the solar collecting system from each end and is drawn through to a plenum section created when the two collectors are joined. Solar radiation is transmitted through the cover plate and is absorbed by a black, sheet metal absorber plate. Heat is gained by passing ambient air over the 384 square feet of absorber plate.

The solar collecting system is connected to a 7.5 Hp aeration fan by a series of 18 inch diameter flexible ducts. These ducts are attached to a square plywood doghouse that encloses the fan. The fan creates the suction force needed to draw air through the solar collectors. A damper, attached to the plywood doghouse, allows outside air to enter the grain bin when areation is needed.

High moisture corn is first dried by a Butler continuous flow dryer to a moisture content of approximately 20%. The corn is then moved to a storage bin where solar heated air finishes the drying process. Soybeans and wheat drying will rely totally on solar heated air.

Cost

The total cost breakdown is divided into two categories:

1)	Solar Dryer	$1,872.04
2)	Air Duct System	225.00

With a total of $2,097.04 an average of $5.46 was spent per square foot of collector.

Construction and Operating Suggestions

* Completely seal the solar collecting system against air leaks. An air tight system has a higher performance.
* Firmly anchor the portable collector to the ground.
* Keep collector surface free of debris. Debris buildup will decrease solar transmittance thus decreasing performance.
* Preserve all wood building materials by painting with an oil base paint.

Suggested Modifications

From our experiences with the University of Purdue design, the following suggestions are given to modify this solar system.

* Locate solar dryers as close to the grain bins as possible. This will minimize the cost of the duct system.
* When connecting the duct system to the fan, allow for a damper to let outside air to pass through the grain bin. This will enable aeration when needed.

Randy Mills Farm

Randy Mills is a young ambitious farmer located in Chesterfield County in the northeastern part of the state. His farming operation consists of 450 acres of rented land and about 100 acres of land which he owns himself. Each year Mr. Mills varies his total acreage of each crop depending on its projected value. His cropping rotation consists of corn and a double cropping of soybeans after wheat.

Mr. Mills owns an in-bin drying and storage facility with a total capacity of 11,000 bushels. One 7.5 Hp fan services two 5,500 bushel bins manufactured by Circle Company. A portable auger helps facilitate the handling of grain into and out of the storage bins. (See Figure A-4.)

Goals

In order to obtain maximum utilization the following objectives were used to design and construct this solar collecting system:

* Provide air to the in-bin drying system when the moisture content of corn is greater than 20%.
* Provide supplemental heat to finish drying corn that is less than 20% moisture content following the in-bin dryer.
* When needed, wheat and soybeans will be dried with solar heated air.

System Description

This solar drying system consists of two 12' by 16' portable collectors designed by the University of Purdue. (See Appendix Figure A-1.) This basic design has a 3.5 inch deep air channel between a plywood back plate and the absorber plate. Another 3.5 inch deep air channel between the absorber and a transparent cover plate allows air to enter the collectors through a cross-sectional area of 7 square feet. The two portable collectors are joined together to create a 32 feet long air passage. Solar radiation is transmitted through the cover plate and is absorbed by a black sheet metal absorber plate. Heat is gained by passing ambient air over the 384 square feet of absorber plate.

The solar collecting system is connected to a 7.5 Hp aeration fan by a series of 18 inch diameter flexible ducts. These ducts are attached to a square plywood doghouse that encloses the fan. The fan creates the suction force needed to draw air through the solar collectors. A damper

attached to the plywood doghouse allows outside air to enter the grain bin when aeration is needed.

When drying corn, the solar dryer supplies the in-bin drying system with preheated air. Soybeans and wheat are dried with solar heated air only.

Cost

The total cost breakdown is divided into two categories:

1) Solar Dryer	$1,125.00
2) Air Duct System	425.00

With a total of $1,550 an average of $4.03 was spent per square foot of collector. Mr. Mills reduced his total cost by using materials found on the farm.

Construction and Operating Suggestions

* Completely seal the solar collecting system against air leaks. An air tight system has a higher performance.
* Firmly anchor the portable collector to the ground.
* Keep collector surface free of debris. Debris buildup will decrease solar transmittance thus decreasing performance.
* Preserve all wood building materials by painting with an oil base paint.

Suggested Modifications

From our experience with the University of Purdue design the following suggestions are given to modify this solar system:

* Locate solar dryers as close to the grain bin as possible. This will minimize the cost of the duct system.
* When connecting the duct system to the fan, allow for a damper to let outside air to pass through the grain bin. This will enable aeration when needed.

Robert Brabham Farm

Robert Brabham is a row crop farmer in the Savannah Valley region of South Carolina. His farm is located on U.S. 64 approximately 20 miles from Bamberg, the county seat. His crops consist of 100 acres of corn along with double cropping soybeans and wheat. Mr. Brabham also operates a small farrow-to-finishing hog operation to supplement his farm income.

A small grain storage facility dries and stores the crops Mr. Brabham produces. The facility consists of two 5,000 bushel grain bins with a propane burner attached to a 7.5 Hp aeration fan. A portable auger is used to load and unload the bins. (See Appendix Figure A-5.)

X 400

Goals

In order to obtain maximum utilization the following objectives were used to design and construct this solar collecting system:

* Provide preheated air to his in-bin dryer to dry corn with a moisture content greater than 20%.
* Provide solar assisted drying of corn below 20% moisture content.
* When needed, solar heat will be used to dry soybeans and small grain.

System Description

This solar drying system consists of two 12' by 16' portable collectors designed by the University of Purdue. (See Appendix Figure A-1.) The basic design has a 3.5 inch deep air channel between a plywood back plate and the absorber plate. Another 3.5 inch deep air channel between the absorber and a transparent cover plate allows air to enter the collectors through a cross-sectional area of 7 square feet. The two portable collectors are joined together allowing air to be drawn through the solar dryer from each end. Solar radiation is transmitted through the cover plate and is absorbed by a black sheet metal absorber plate. Heat is gained by passing ambient air above and below the 384 square feet of absorber plate.

The air duct system consists of a square sheet metal doghouse that encloses a 7.5 Hp aeration fan. A 32 inch diameter sheet metal duct attaches the solar collector to this sheet metal enclosure. The fan creates the suction force needed to draw air through the collector. A damper located near the fan allows the grain to be aerated when necessary.

The solar dryer provides preheated air to the in-bin drying system. This pre-heated air reduces the temperature differential needed to dry high moisture corn. When the moisture content reaches approximately 20%, the burner is no longer needed and solar heated air reduces the moisture content to 12% wet basis.

Cost

The cost breakdown is divided into two categories:

1)	Solar Dryer	\$1472.32
2)	Air Ducting System	625.00

With a total cost of \$2,097.32 an average of \$5.46 was spent per square foot of collector.

Construction and Operating Suggestions

* Completely seal solar collecting system against air leaks. An air tight system has a higher performance.
* Firmly anchor the portable collector to the ground.
* Keep collector surface free of debris. Debris buildup will decrease solar transmittance thus decreasing performance.

* Preserve all wood building materials by painting with an oil base paint.

Suggested Modifications

* Locate solar dryers as close to the grain bins as possible. This will minimize the cost of the air duct system.
* When connecting duct system to the fan, allow for a damper to let outside air pass through the grain column. This will enable aeration when needed.

Steve Lewis Farm

Steve Lewis is a large farmer located off of U.S. 321 near Allendale, South Carolina. This 2,000 acre farm in the southeastern part of the state has a cropping rotation of corn, wheat, soybeans and a 100 acre peanut base. Since South Carolina is experiencing unusually dry summers, Mr. Lewis uses center pivot irrigation systems on his corn and peanut crops.

Mr. Lewis operates a grain storage facility on his main farm. His storage system consists of five 21 foot diameter bins. A Shivvers continuous flow dryer takes high moisture grain and reduces the moisture content to a level for safe storage. Portable augers are used to load and unload the storage bins. (See Appendix Figure A-6.)

Goals

In order to obtain maximum utilization the following objectives were used to design and construct this solar collecting system:

* Provide supplemental heat to dry corn with a moisture content less than 20 percent.
* When needed, wheat and soybeans will be dried with solar heated air.

System Description

This solar drying system consists of two 12' by 16' portable collectors designed by the University of Purdue. (See Appendix Figure A-1.) This design has a 3.5 inch deep air channel between a plywood back plate and the absorber plate. Another 3.5 inch deep air channel between the absorber and a transparent cover plate allows air to enter the collectors through a cross sectional area of 7 square feet. The two portable collectors are joined together thus allowing air to be drawn through the collector from each end. Solar radiation is transmitted through the cover plate and is absorbed by a black sheet metal absorber plate. Heat is gained by passing ambient air above and below the 384 square feet of abosorber plate.

The solar collecting system is connected to a 10 horsepower aeration fan by a series of 18 inch diameter flexible ducts. These ducts are attached to a square plywood doghouse that encloses the fan. The fan creates the suction force needed to draw air through the solar collectors.

A damper attached to the plywood doghouse allows outside air to enter the grain bin when aeration is needed.

High moisture corn is first dried in the Shrivvers drier then moved to the storage bin with the attached solar dryer. Solar heated air finishes the drying process.

Cost

The total cost breakdown is divided into two categories:

1)	Solar Collectors	$2,541.62
2)	Air Duct System	645.80

With a total cost of $3,187.42 an average of $8.30 was spent per square foot of collector. Mr. Lewis hired outside labor to construct his solar drying system. If farm labor were used, the average cost per square foot of collector would have been reduced by approximately $3.00 per square foot.

Construction and Operating Suggestions

* Completely seal solar collecting systems against air leaks. An air tight system has a higher performance.
* Firmly anchor the portable collector to the ground.
* Keep collector surface free of debris. Debris buildup will decrease solar transmittance thus decreasing performance.
* Preserve the construction materials by painting with an oil based paint.

Suggested Modifications

From our experience with the University of Purdue design the following suggestions are given to modify this solar system:

* Locate solar dryers as close to the grain bins as possible. This will minimize the cost of the duct system.
* When connecting the duct system to the fan, allow for a damper to let outside air to pass through the fan. This will enable aeration when needed.

<u>Edward Cribb Farm</u>

Edward Cribb operates a farm in Darlington county in the northeastern section of the state known as the Great Pee Dee River Drainage Area. This tobacco and row crop farm lies approximately 11 miles from Darlington, South Carolina. The Cribb farm produces 55 acres of tobacco which is cured in seven bulk curing barns. His crop rotation consists of corn, soybeans and seed wheat produced for Coker Seed Company.

A 50' by 100' Butler storage building serves as a grain storage facility with a capacity of 40,000 bushels and an equipment storage shed. Moisture is removed from the grain by a Butler Kansun high temperature dryer and then augered into the storage building. An overhead auger

evenly distributes the grain throughout the building. Permanent augers mounted below the floor unload the building into his tandem trailer trucks. (See Appendix Figure A.)

Goals

In order to obtain maximum utilization the following objectives were used to design and construct this solar collecting system:

* Provide solar assisted heat to dry corn below 20% moisture content.
* Provide supplemental heat for tobacco curing.
* Provide shop heat during the off-season.

System Description

The preliminary proposal for this farm utilized solar energy in drying grain, however, Mr. Cribb feels curing tobacco with solar energy has its place on his farm. This year research was conducted on one of Clemson's experimental farms to determine what variations in curing schedule and design changes of curing barns are needed to make drying with solar energy feasible. Next year Mr. Cribb plans to modify one of his barns to accommodate the use of the two portable collectors already constructed.

W. B. Boykin Farm

Mr. Boykin is a row crop farmer located on U.S. 521 near Rembert, South Carolina. Mr. Boykin has a Ph.D degree in Agronomy and grows corn, wheat, milo and has a 60 acre peanut allotment on his Kershaw county farm. He also operates a fertilizer dealership along with a custom spreading and herbicide spraying business.

Five bins used for storing small grains and two bins used to store peanuts comprise this 25,000 bushel storage facility. A PTO driven high temperature dryer feeds an overhead auger that loads the dry grain into the five storage bins. A portable auger loads his peanut storage bins.

Goals

In order to obtain maximum utilization the following objectives were used to design and construct this solar collecting system:

* Provide solar assisted drying of corn below 20% moisture content.
* Dry milo and wheat with supplemental solar heat when needed.
* Cure peanuts with solar heat.
* Provide shop heat during off-drying times.

System Description

The solar collecting system used on this farm consists of a 24' long by 12' wide portable collector designed by the University of Illinois. (See Appendix Figure A-8.) Solar radiation is transmitted through a transparent cover plate and is absorbed by a plywood absorber. This plywood absorber, painted black, also serves as the back plate of the collector. Ambient air enters the collector from the inlet located

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at the top and is drawn through a series of air channels having a cross-sectional area of .4 square foot before it exits the collector from the bottom into a storage plenum. Air is stored in the plenum until it is exhausted through the grain column.

A plywood box is constructed around a 10 Hp aeration fan. A series of 18" ducts connect the storage plenum to the plywood enclosure. The fan creates the suction force needed to draw air through the collector. An attached damper allows for aeration when needed.

A PTO driven high temperature dryer reduces the moisture content of corn to approximately 20%. Solar heated air then finishes the drying process.

Cost

The total cost breakdown is divided into two categories:

1) Solar Dryer	$1,047.20
2) Air Duct System	225.00

With a total cost of $1,272.20 an average of $4.41 was spent per square foot of collector.

Construction and Operational Suggestions

* Completely seal solar collecting systems against air leaks. An air tight system has a higher performance.
* Firmly anchor the portable collector. This collector has the capability of being easily turned over by having a high center of gravity.
* Keep collector surface free of debris. Debris buildup will decrease solar transmittance thus decreasing performance.
* Preserve all wood building materials by painting with an oil base paint.

Suggested Modifications

From our experience with the University of Illinois design the following suggestions are given to modify this solar system:

* Locate solar dryers as close to the grain bins as possible. This will minimize the cost of the air duct system.
* When connecting the duct system to the farm, allow for a damper to let outside air to pass through the fan. This will enable aeration when needed.

<u>Doc and Mike Streater Farm</u>

A father and son partnership, Doc and Mike Streater, operate a small row crop and truck farm in Chesterfield county. This 30 acre farm near the North Carolina border grows a rotation of corn, soybeans and small grains. In addition to their row crops, they grow vegetables such as okra, sweet corn, sweet potatoes and butter peas. All crops produced on this farm are grown organically.

The Streaters built a 24' by 28' barn with an attached greenhouse. The barn functions as a combination shop area and grain storage facility. Their storage facility consists of four 7' by 9' by 8' grain bins, each having a capacity of approximately 400 bushels. Two bins are served by a 1.5 Hp fan. The 8' by 28' greenhouse supplies heat to dry grain and also to start vegetable plants. (See Appendix Figure A-11.)

Goals

In order to obtain maximum utilization the following objectives were used to design and construct this solar system.

* Provide solar heated air to dry grain.
* Provide storage in 400 bushel lots.
* Cure sweet potatoes under more controlled conditions than current procedures.
* Heat the solar greenhouse section for plant propagation.
* Heat the shop area during the off-season.

System Description

This solar collecting system was designed to serve many purposes on this small farm. A majority of the building materials can usually be found lying about on any farm. The entire roof of the 24' by 28' shop and storage area faces south and functions as a bare plate collector. The sheet metal roof is painted black to increase solar absorption. The roof is framed with 2" x 8" rafters placed 2' on center to form a series of air channels each having a cross-sectional area of 1.2 square feet. A layer of .75 inch insulating board is placed under the rafters to keep the heated air flowing through the channels.

Ambient air is drawn through the bare plate collector into an attached greenhouse. The 8' by 28' greenhouse section serves as both an air storage plenum and a solar collector. The greenhouse is covered with a transparent cover material to allow solar radiation to collect in the crushed rock floor. Solar heat is stored in this 5 inch layer of crushed rock thus keeping the greenhouse warm at night during cool periods. The greenhouse also houses the two fans and the distribution duct to the four grain bins. The fans deliver heated air to the bins for crop drying and also heat to the shop during the off-season. (See Appendix Figure A-10.)

Cost

No cost estimates are available now.

Construction and Operating Suggestions

* Install a ventilation system in the greenhouse to ensure a proper growing environment.
* Completely seal the greenhouse against air leaks. An air tight system has a higher performance.
* Keep collector surface free of debris. Debris buildup will decrease solar transmittance thus decreasing performance.

Suggested Modifications

From our experiences with this solar collecting system, the following suggestions are given to modify this solar system:

* Install an auxiliary heater for cold cloudy days.
* Install insulating curtains on the greenhouse roof and walls to reduce supplemental heat loss on cold nights.

Jimmy Watkins Farm

Jimmy Watkins operates a crop-livestock farm located in Saluda County in the lower Piedmont section of South Carolina. It lies between the towns of Saluda and Greenwood on U.S. 178. He raises about 200 acres of corn and 400 acres of soybeans and small grains. A majority of the grain is fed on the farm to his dairy herd and hog finishing operation.

High moisture grain is removed from the field and temporarily stored in a wet holding bin before it is fed into a PTO driven high temperature dryer. This converted batch dryer continuously dries grain before being augered off to be stored. A series of six bins store the diverse number of crops he produces for animal feed. (See Appendix Figure A-12.)

Goals

In order to obtain maximum utilization, the following objectives were used to design and construct this solar collecting system:

* Provide supplemental heat to dry corn following a high temperature dryer.
* When needed, small grain drying will rely on solar heated air.
* Soybeans will be dried with natural air with the solar system serving as a backup when needed.
* The dairy operation will use the solar system for preheating water and the milking parlor.

System Description

When building a new dairy facility on the farm, Mr. Watkins incorporated a solar collecting system on the roof of his holding area. In order to construct the air channels needed for this bare plate collector, modification in roof design consisted of orientating 2" x 6" purlins on edge to run east to west and enclosing the underside of the rafters to form the back plate of the collector were necessary. Mr. Watkins placed vegetable sheathing board on the underside of the rafters because of the relative expense of the material.

Ambient air gains heat as it is drawn through the series of air channels, each having a cross-sectional area of 1.3 square feet, before exiting into a storage plenum.

Mr. Watkins built a concrete block shed that encloses both the PTO driven dryer and the tractor that operates it. This shed is attached to the storage plenum by a 30" by 30" plywood duct, thus allowing the dryer

fan to pull air through the solar collecting system.

High moisture grain is removed from the field and temporarily stored in a wet holding bin before being augered to the continuous flow dryer. The solar collecting system preheats ambient air before reaching the dryer thus decreasing the normal temperature differential needed for drying high moisture grain. Heat dissipation from both the tractor and fan motor is also utilized in this system.

Cost

The total cost breakdown is divided into two categories:

1) Solar Collectors	$2,541.62
2) Air Duct System	645.80

Mr. Watkins estimated that an additional cost of $8,000 was spent on extra materials and labor to construct his solar grain drying system. With proper maintenance this solar dryer should recover the initial investment of $3.00 spent per square foot of collector.

Construction and Operating Suggestions

* Completely seal solar collecting system against air leaks. An air tight system has a higher performance.
* Keep collector surface free of debris. Debris buildup will decrease solar transmittance thus decreasing performance.
* Preserve the construction materials by painting with an oil base paint.

Suggested Modifications

From our experience with the University of Illinois design the following suggestions are given to modify this solar system:

* Locate solar dryers as close to the grain bins as possible. This will minimize the cost of the air duct system.
* When connecting the duct system to the fan, allow for a damper to let outside air to pass through the fan. This will enable aeration when necessary.

SOLAR HEAT GRAIN EXPECTATIONS

Solar grain dryers convert solar radiation into usable energy by passing ambient air over an absorber plate with the total amount of energy collected being related to weather conditions. This section is designed to give the reader an overall estimation of total heat gain for the state of South Carolina.

A major factor affecting the amount of heat gain collected by the system depends on the intensity of the solar radiation striking the absorber plate. On clear days maximum radiation is made available to be absorbed by the collector. However, cloud cover reduces solar radiation thus

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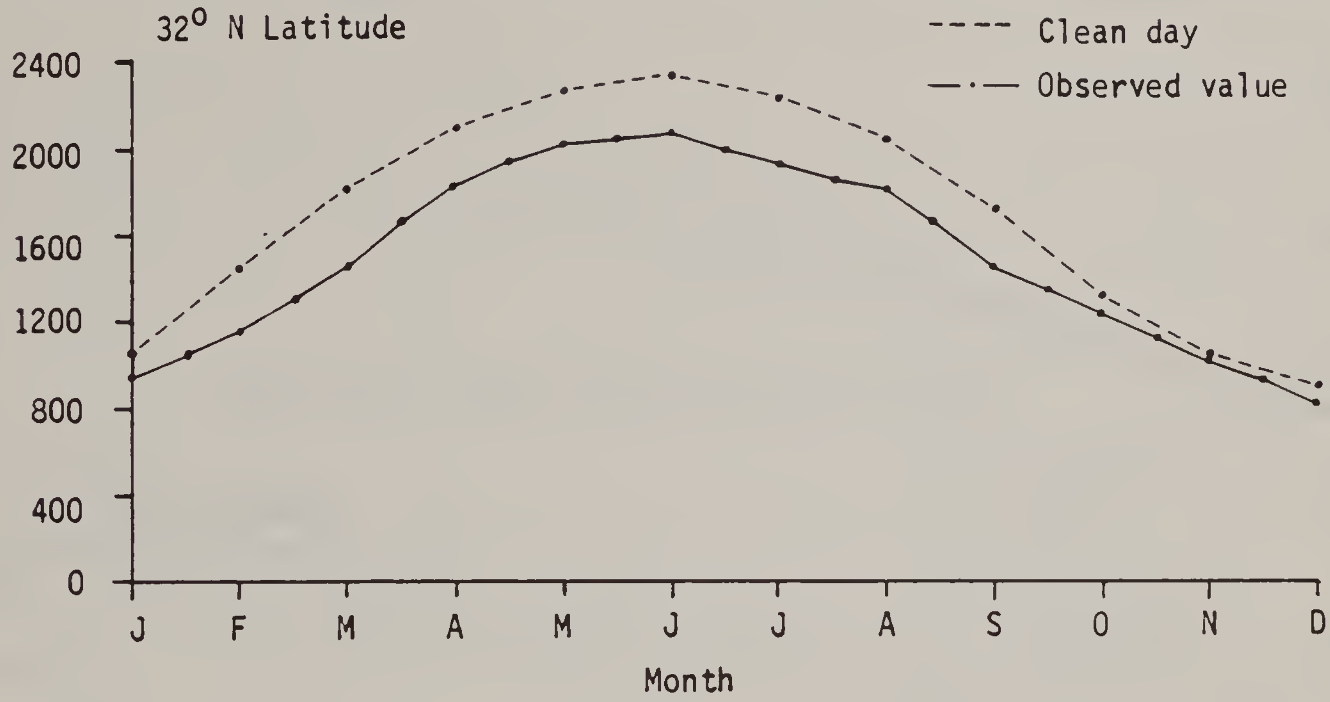
Figure 1.

AVERAGE DAILY SOLAR HEAT GAIN FOR A CLEAR DAY VS. OBSERVED SOLAR HEAT GAIN*



*Solar Heating and Cooling of Residential Buildings, Solar Energy Applications Laboratory, Colorado State University. October 1977.

Figure 2. Cloudiness -- Mean Number of Days

Month	Clear	Partly Cloudy	Cloudy
January	10	6	15
February	10	6	12
March	10	8	13
April	10	9	11
May	8	10	13
June	8	10	12
July	5	13	13
August	8	13	10
September	9	10	11
October	15	5	10
November	13	7	10
December	11	6	14

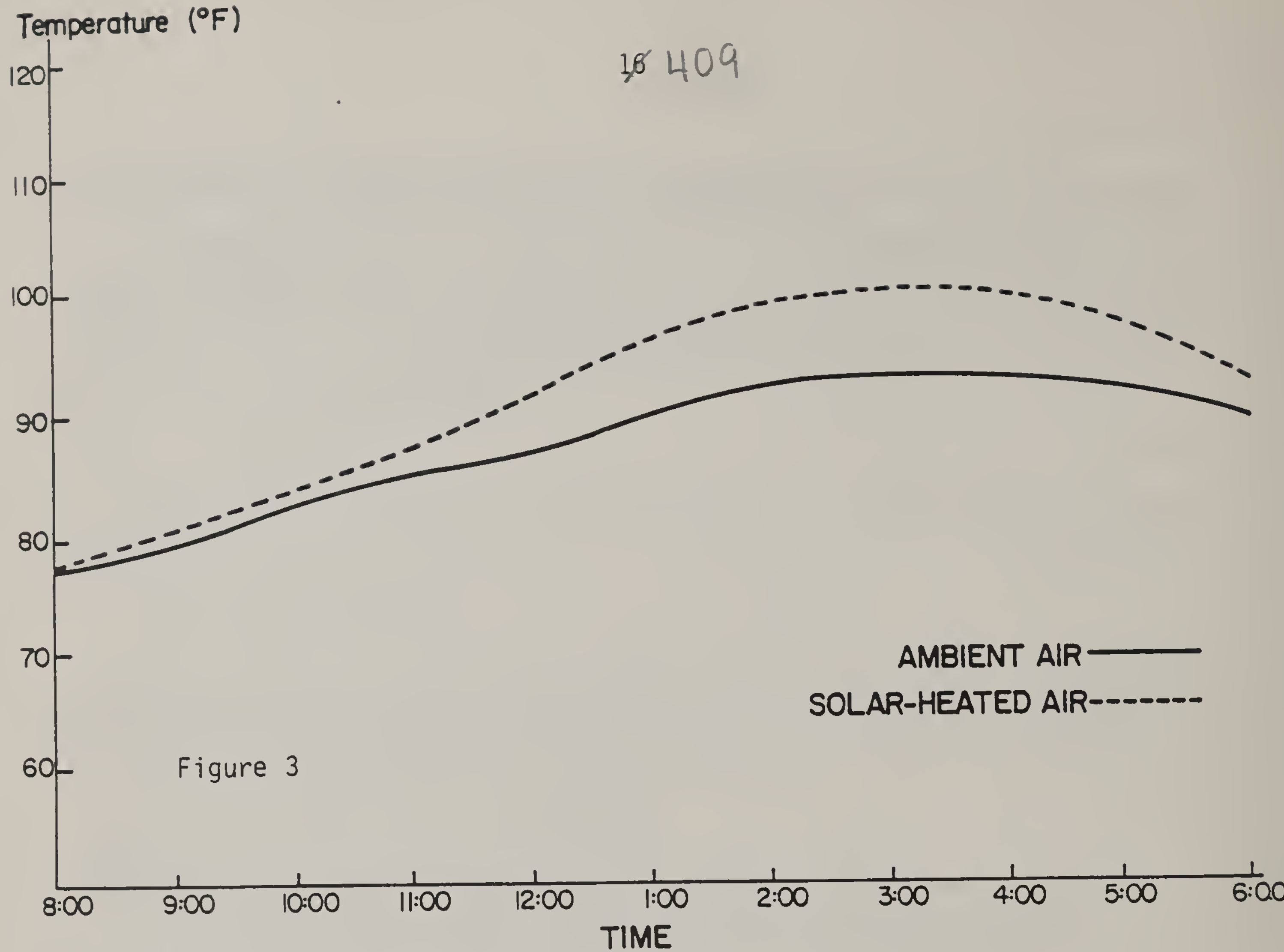


Figure 3

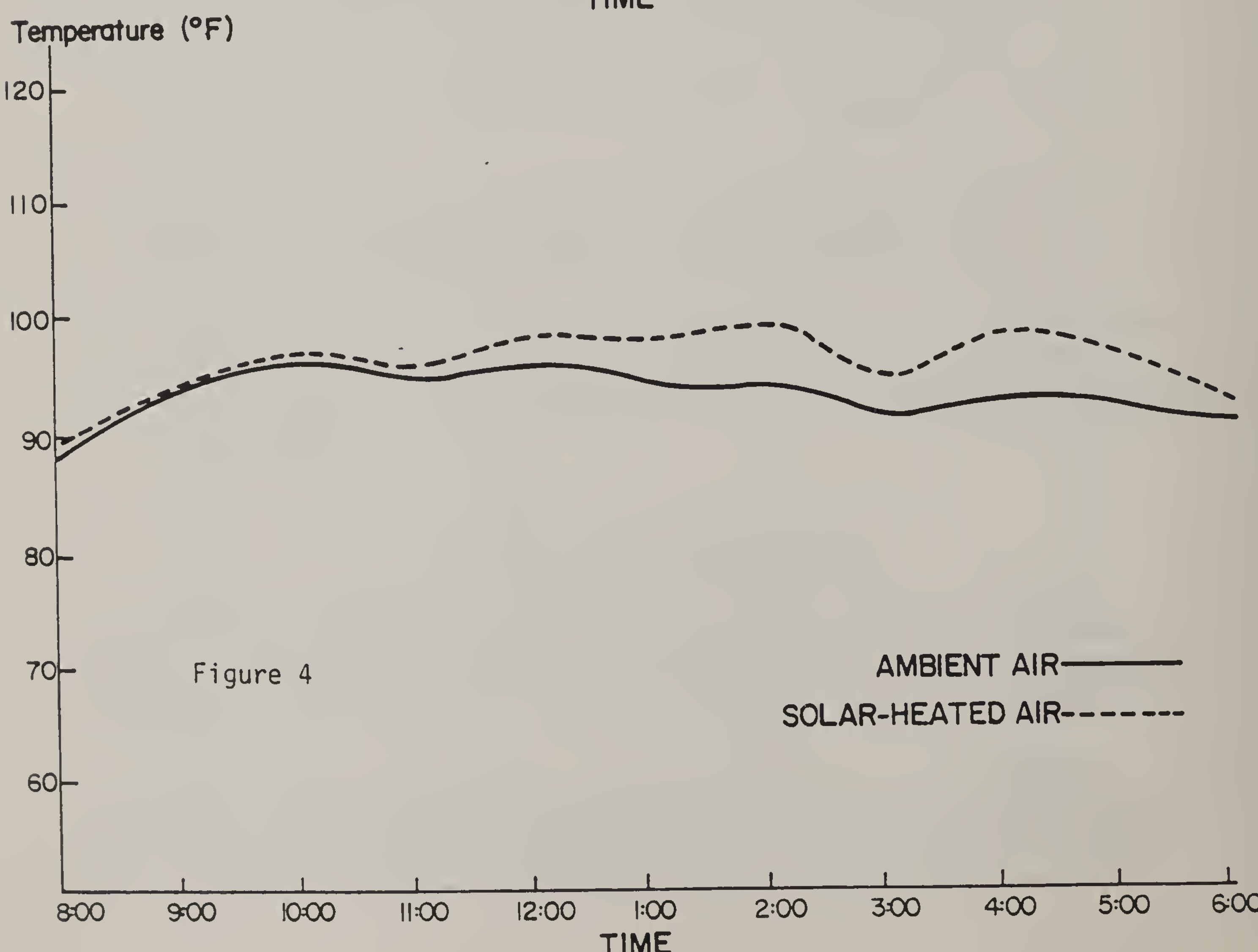
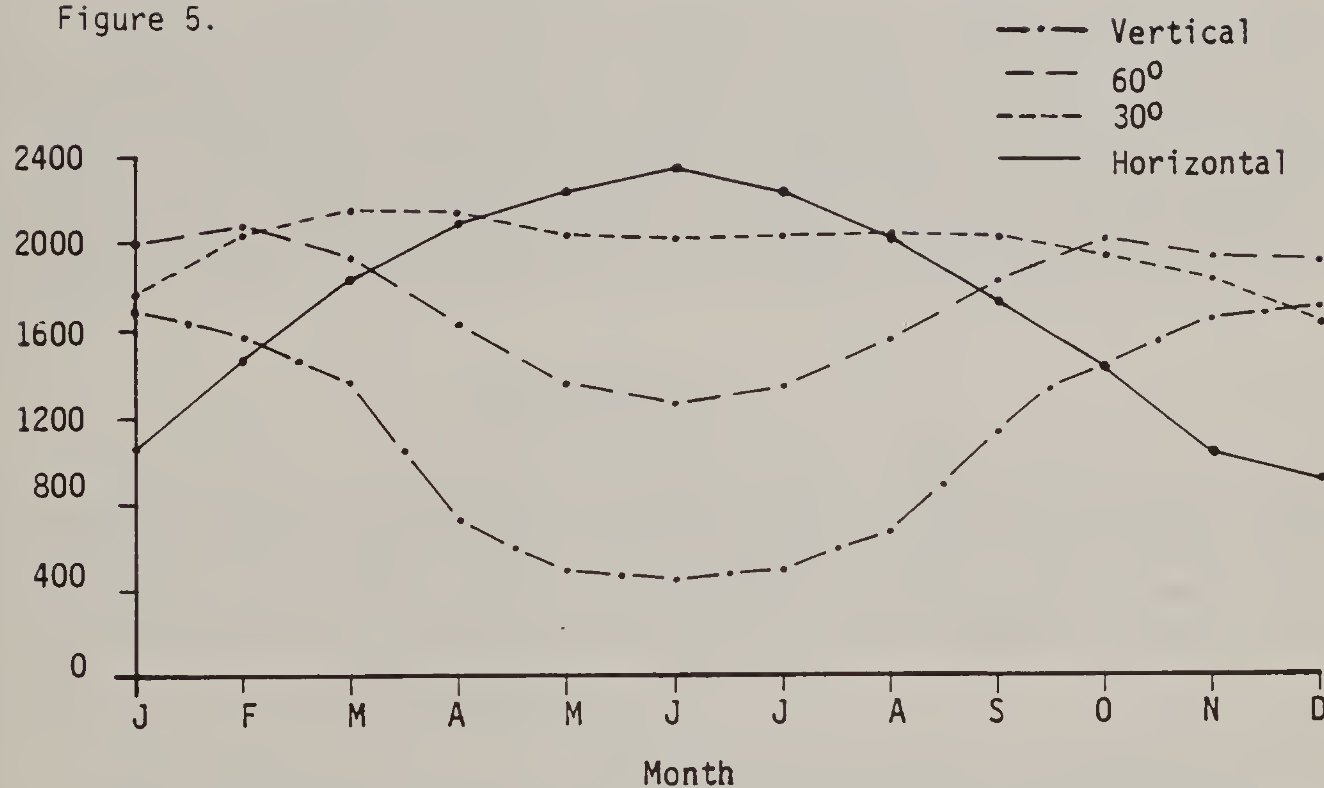


Figure 4

AVERAGE DAILY SOLAR HEAT GAIN FOR A CLEAR DAY+

Figure 5.



+ The Passive Solar Energy Book, Edward Mazria, Rodale Press, 1979.

decreasing heat gain. In Figure 1 average daily solar radiation for a clear day is compared with observed values taken from South Carolina weather stations. This figure illustrates the reduction of radiation between clear versus cloudy days with the difference depending on the percentage of sunshine.

Figure 2 illustrates for our location the average number of days in a month which are clear, partly cloudy or cloudy. These values give an estimation of the percentage possible sunshine for each month, thus giving the reader some criteria to follow when designing solar systems for our location. Illustrations of how clear day versus cloudy day affects the performance of solar collectors used in this project can be seen in Figures 3 and 4, respectively.

Solar inclination changes throughout the year thus creating the need for changing collector tilt angle so that radiation strikes the absorber at a proper angle. By reducing reflection losses more solar radiation is made available to the absorber plate thus creating larger heat gains. Figure 5 illustrates the amount of solar radiation for a clear day versus various tilt angles for our location through the year. These values will help estimate the possible heat gain from solar collecting system due to collector angles, thus giving an idea on what to expect when using solar energy.

DEMONSTRATIONS

Due to the rising costs of natural fuels, solar energy is now playing a vital role as an alternative energy source. The main purpose of the On-Farm Solar Grain Drying Project is to demonstrate how solar energy can be applied to agriculture. During the 1982 fall drying season, two on-farm sites were set up to demonstrate the use of solar energy in drying grain.

Francis Kearse, Bamberg County

The demonstration on the Kearse farm was held in conjunction with the Bamberg County Soybean tour. The tour consisted of six stops on local farms to demonstrate the use of various soybean varieties and solar energy in drying grain.

A 30 minute presentation was given to approximately 50 local farmers. The presentation consisted of a brief explanation on the origin of the project and then a demonstration was held. Construction of the collectors, cost estimates, performance, and various applications of the solar grain dryers were discussed during the demonstration.

Jimmy Watkins, Saluda County

The demonstration on the Watkins' farm showed approximately 40 area farmers how solar collecting systems can be incorporated in the design of newly constructed agricultural buildings. An explanation on converting a sheet metal roof to a bare collector demonstrated to these farmers that they could build a solar collecting system on their farm.

Orientating the roof east to west was stressed in order to obtain maximum solar radiation. Alterations in the design of the building and cost estimates of the solar collecting system was discussed. After the talk, the solar collecting system was put into operation to demonstrate the temperature increase between ambient versus exhausted air.

MONITORING OF THE SOLAR DRYING SYSTEMS

Monitoring of the solar grain dryers consists of copper constentan thermocouples placed at various locations throughout the system. The thermocouple placement detects the increase in temperature of the ambient air as it passes through the solar dryer before exiting through the grain storage bin. This temperature differential will aid in the determination of the overall performance of the solar grain drying system.

The thermocouples are attached to recording data logers that were purchased for this project. These recorders continuously scan the thermocouples at a pre-set interval and record the data on magnetic tapes. During crop drying, the data logers are placed on the demonstration farms to automatically record the temperature data. With the use of a data acquisition software package on the computer, a printout of the data can be obtained for analysis.

Grain spoilage is a major problem that plagues farmers who dry and store their grain. On each of the demonstration farms thermocopules were placed at various locations throughout the storage bins. These thermocouples enable a farmer to obtain a temperature profile of his grain column. Detection of hot spots and the determination of when aeration is necessary will help these farmers to store their grain more safely.

EDUCATIONAL MATERIALS

Demonstrating solar applications to the agricultural community is the main objective of the project. We have composed a slide set presentation showing the various types of solar collecting systems used on the demonstration farms. A viewer has an opportunity to see the convenience of using portable collectors because of their versatility. Solar collectors that are incorporated with farm buildings are also shown to illustrate a heat collection system for a relatively small extra investment. The various air duct systems used are also illustrated. The presentation allows a farmer to see how he might incorporate the use of solar energy on his farm.

County extension offices now have the capability of using Beta Max presentations for educational purposes. A film strip containing information on the portable collectors is available to these offices. The film strip contains an overview of the Solar Grain Drying Demonstration Project as well as an explanation on the uses of portable collectors. This presentation demonstrates the applications of solar energy as an alternative fuel source.

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SUMMARY

Solar grain drying in South Carolina will be evaluated during 1983-84. Data will be based on nine on-farm systems.

For the benefit of this final report the authors offer the following tentative conclusions and suggestions. These are based on limited testing and data acquisition and are for South Carolina conditions:

1. Heat collectors from air tight panels will average about 800 Btu per square foot of solar collector per day.

2. Collectors based on the Purdue and Illinois design are not readily portable because of size, weight and duct systems.

3. Transistion sections for connecting two or more portable collectors has not been adequately designed and tested for airflow considerations.

4. Design and selection of materials in the Purdue collector at the base of the fiber-reinforced plastic need to be modified to prevent wood damage from rainfall runoff and ground moisture.

5. Ducting to transport heated air from the collector to the grain bin is very expensive and may be prohibitive in order to reduce excessive friction drag on the fan.

6. Solar drying will not become common place in South Carolina within the next ten years. However, some farmers will install solar drying as a result of these demonstrations.

7. South Carolina would not have any solar grain drying installations now (1982) had this cost sharing project not been funded.

8. Crop drying in the southeastern U.S. in general and South Carolina in particular has not been adequately funded in the past. This project has provided training, equipment and instrumentation that will enhance grain drying and storage work in South Carolina for the next decade.

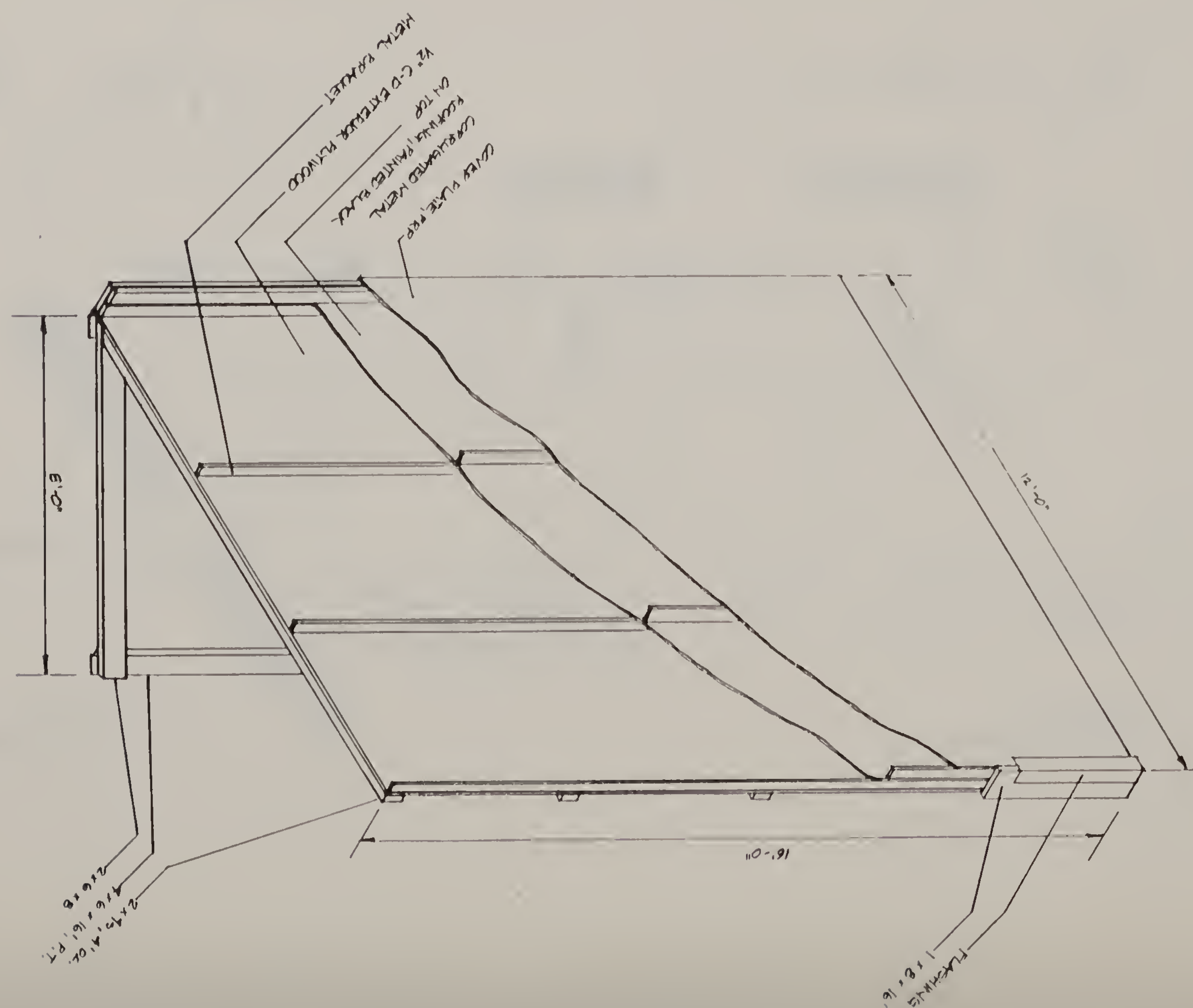
9. Where possible, retrofitting solar collectors should be incorporated into buildings as opposed to free standing collectors.

10. Future demonstration programs should not expect the cooperating states to make ten systems operational within a two year period. Too many unforeseen obstacles arise with farmer cooperators when trying to plan for two or three years in advance.

11. Farmers that have not completed their systems or dropped out completely were forced to do so by the economy, depressed grain prices, family problems or legal entanglements. Price stabilization for fossil fuels in 1982 has dampened the interest in solar that existed in 1980 when the project was begun.

Overall the project will promote the use of solar energy. In addition, these on-farm projects will give educators the chance to present additional programs on grain drying and storage to farmers who attend meetings on solar but not on storage in general. The'piggy back' potential is great.

Figure A-1 Purdue University Collector



SOLAR GRAIN DRYING

RUFUS CRIB

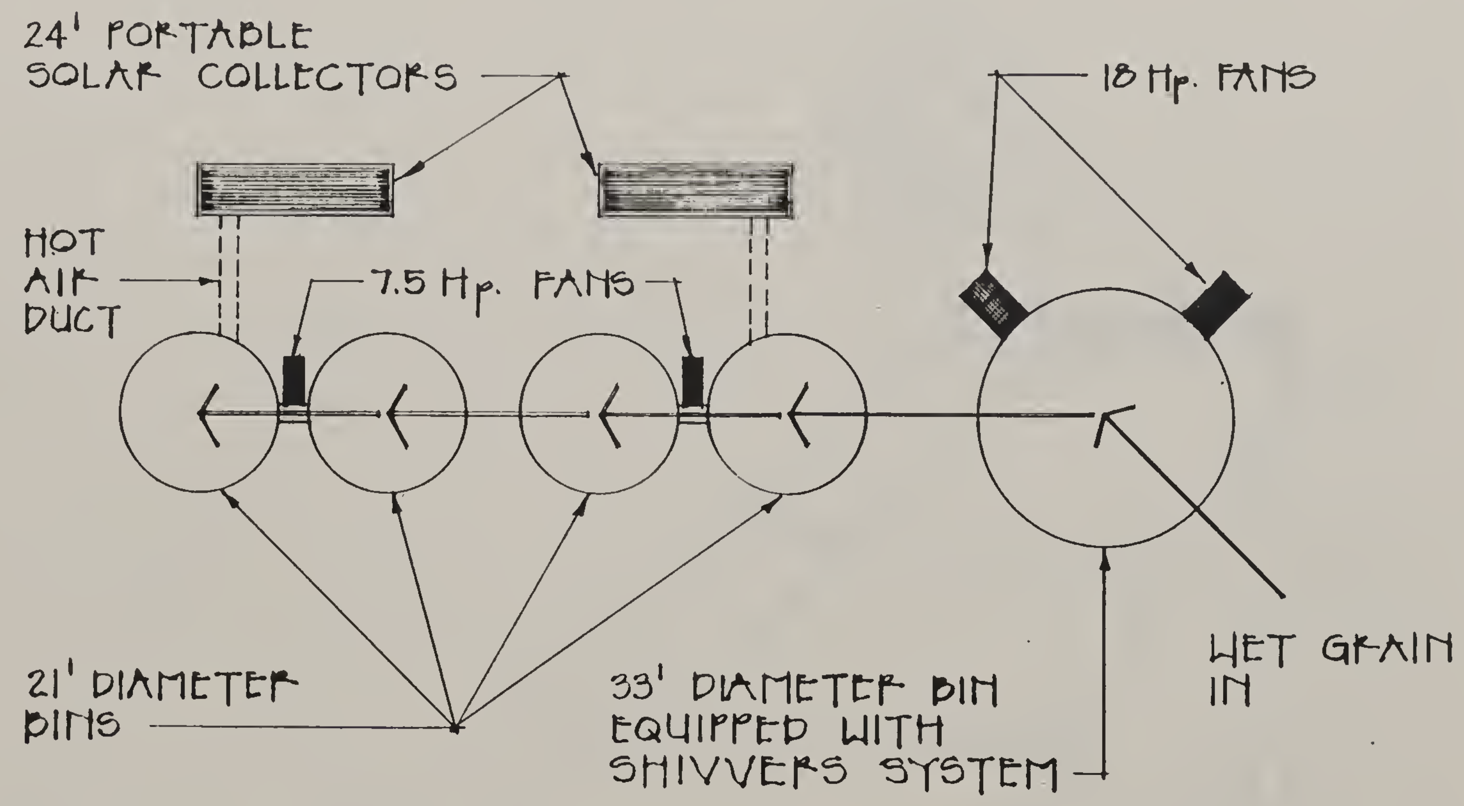


FIG. A-2

FRANCIS KEARSE
BAMBERG CO.

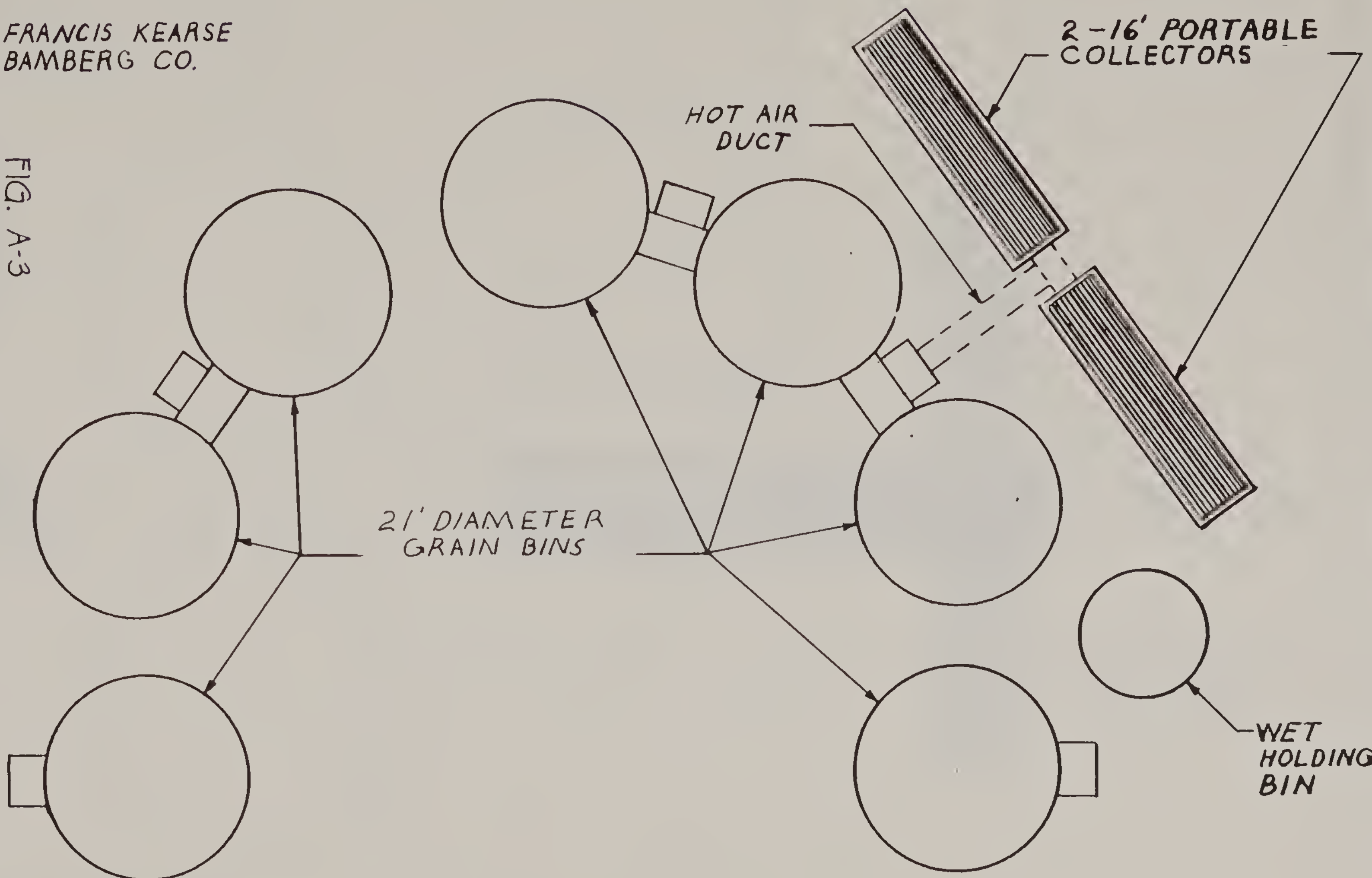


FIG. A-3

RANDY MILLS
CHESTERFIELD CO.

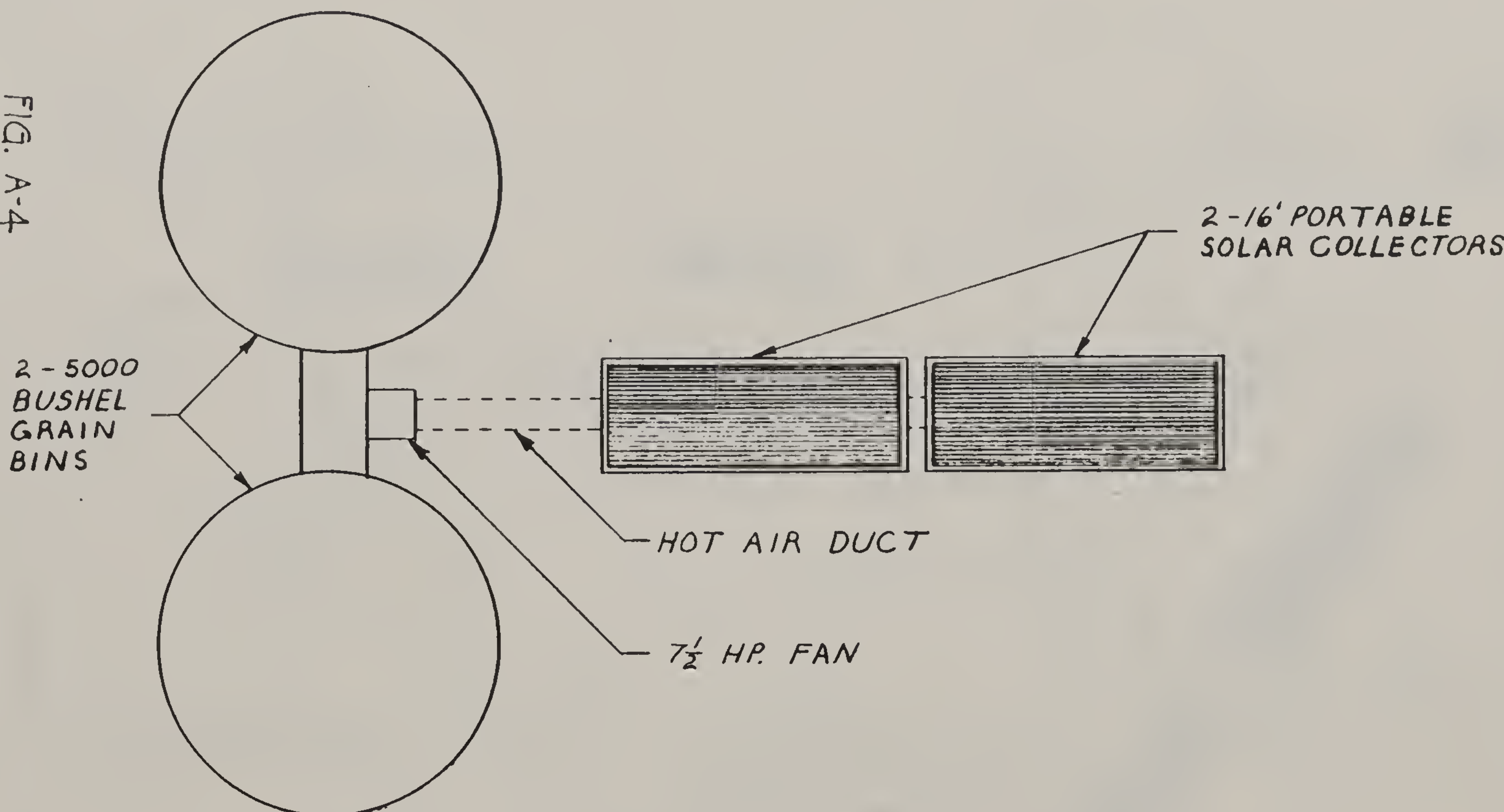


FIG. A-4

ROBERT BRABHAM
BAMBERG CO.

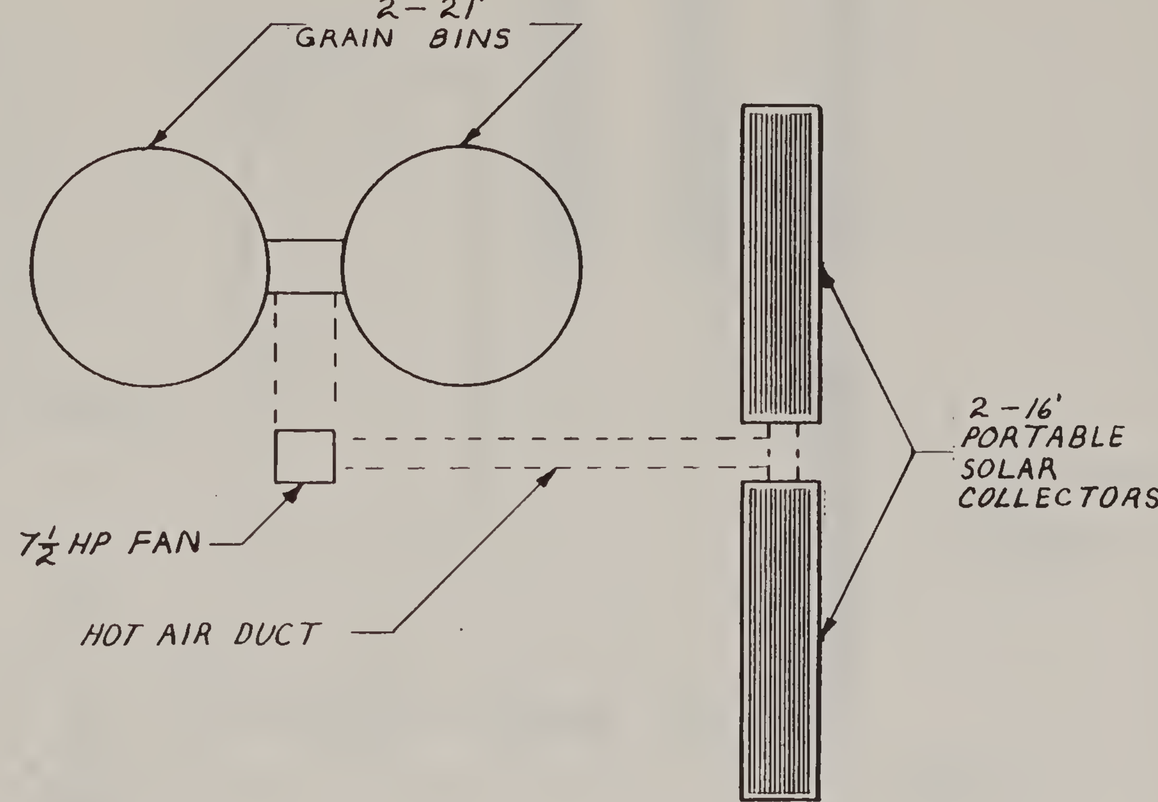


FIG. A-5

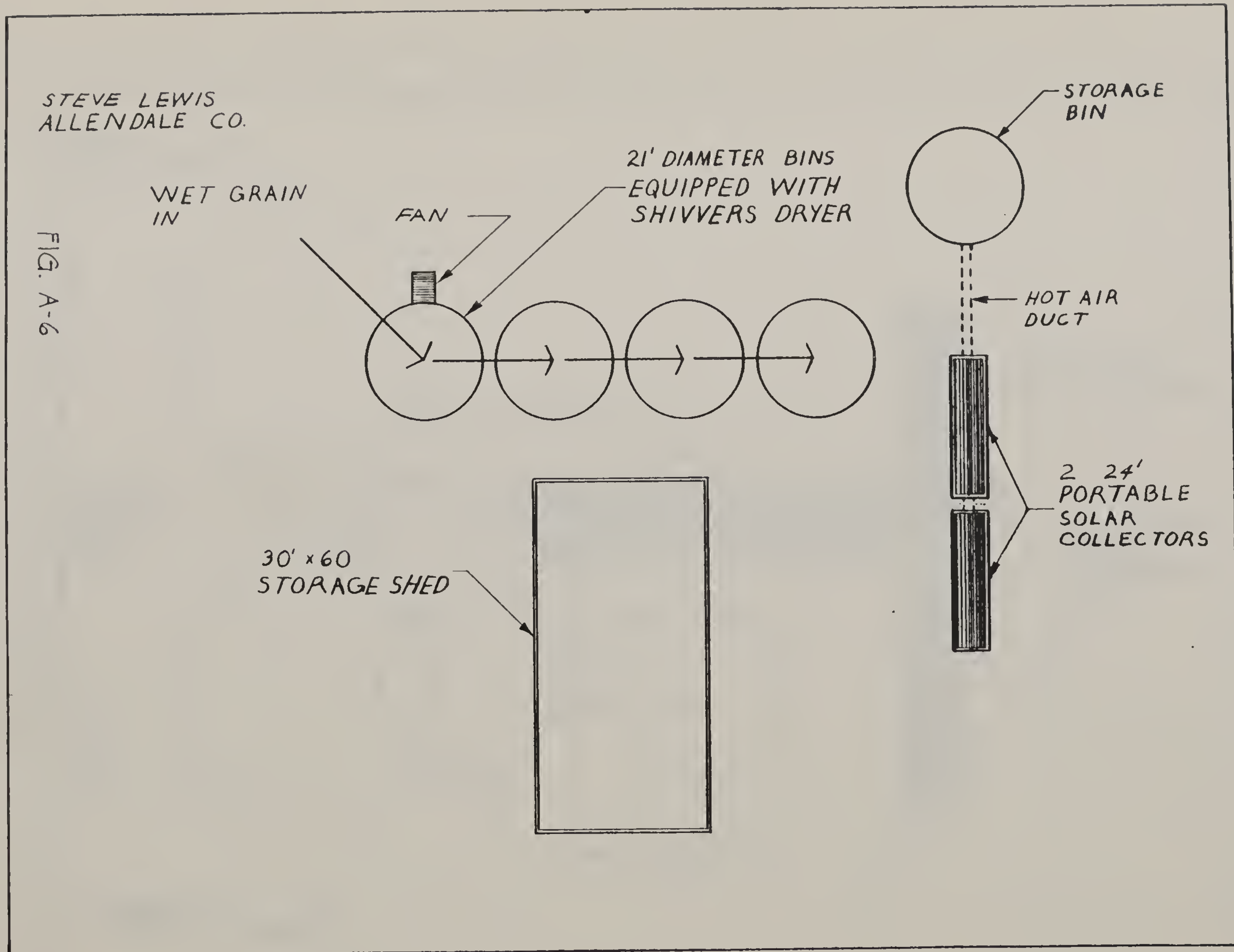

STEVE LEWIS
ALLENDALE CO.
WET GRAIN
IN
FAN
21' DIAMETER BINS
EQUIPPED WITH
SHIVVERS DRYER
STORAGE
BIN
HOT AIR
DUCT
2 24'
PORTABLE
SOLAR
COLLECTORS
30' x 60
STORAGE SHED

FIG. A-6

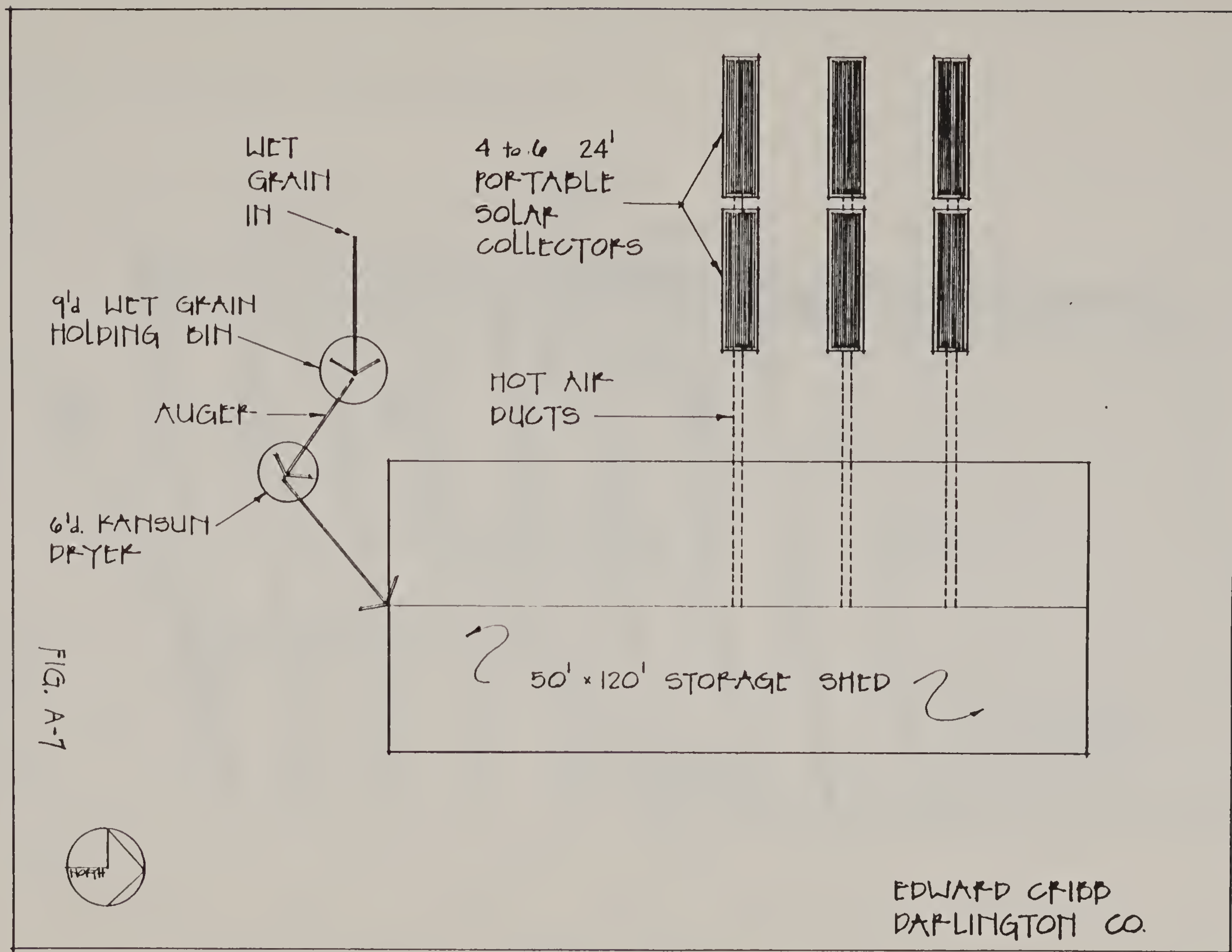

WET GRAIN IN
9'd WET GRAIN HOLDING BIN
AUGER
6'd. KANSUN DRYER
4 to 6 24' PORTABLE SOLAR COLLECTORS
HOT AIR DUCTS
50' × 120' STORAGE SHED
NORTH
EDWARD CRIBB
DARLINGTON CO.

FIG. A-7

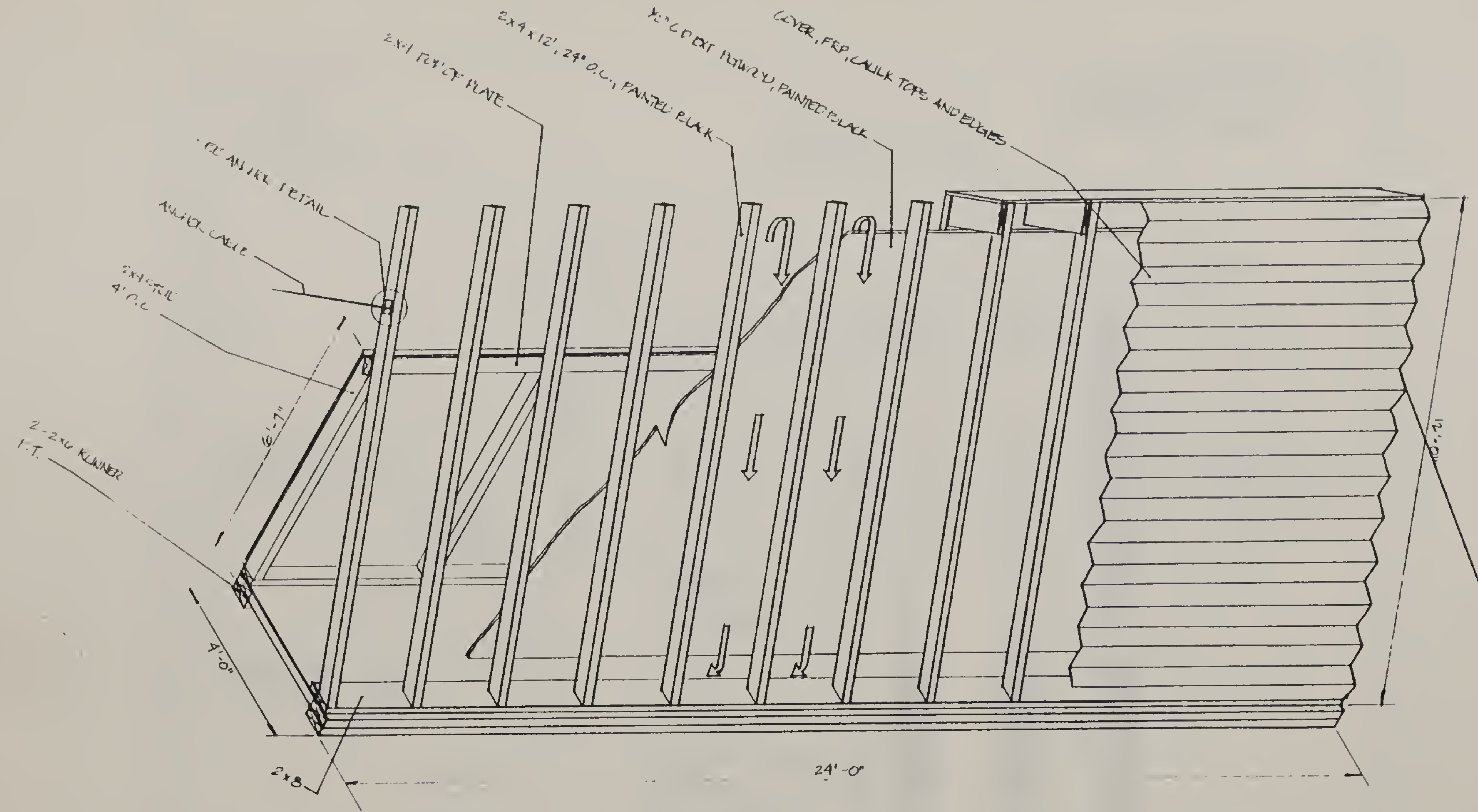


Figure 8-A. University of Illinois Collector

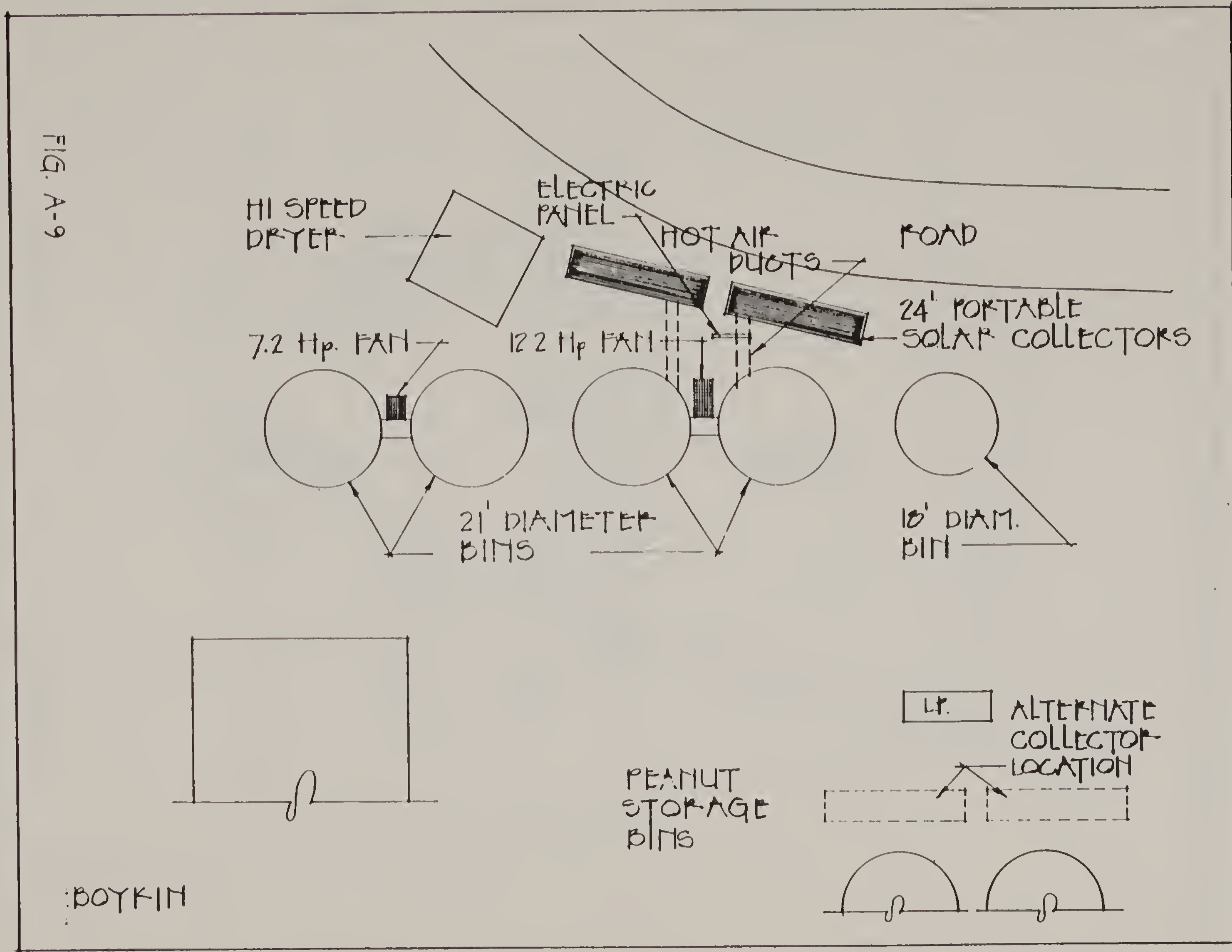
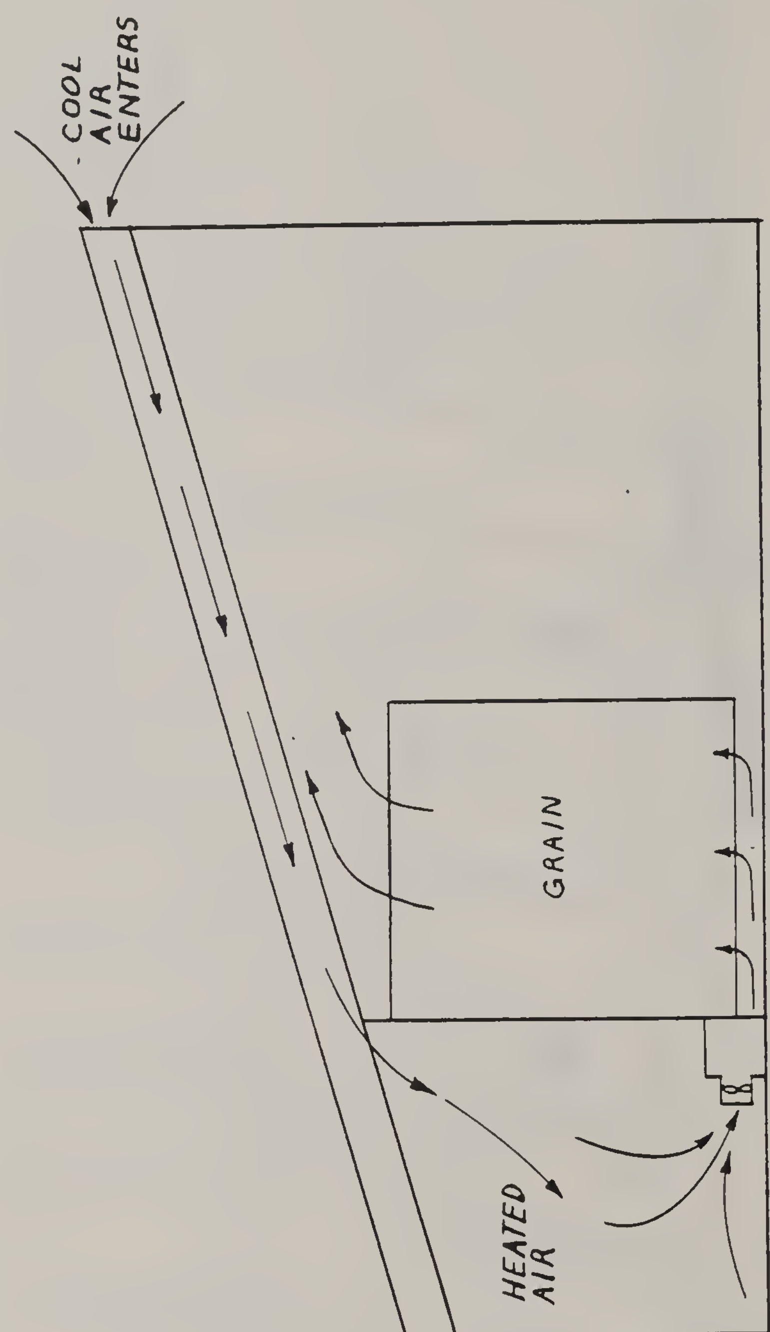

HI SPEED DRYER
ELECTRIC PANEL
HOT AIR DUCTS
ROAD
24' PORTABLE SOLAR COLLECTORS
7.2 Hp. FAN
12 2 Hp FAN
21' DIAMETER BINS
18' DIAM. BIN
LP.
ALTERNATE COLLECTOR LOCATION
PEANUT STORAGE BINS
BOYKIN

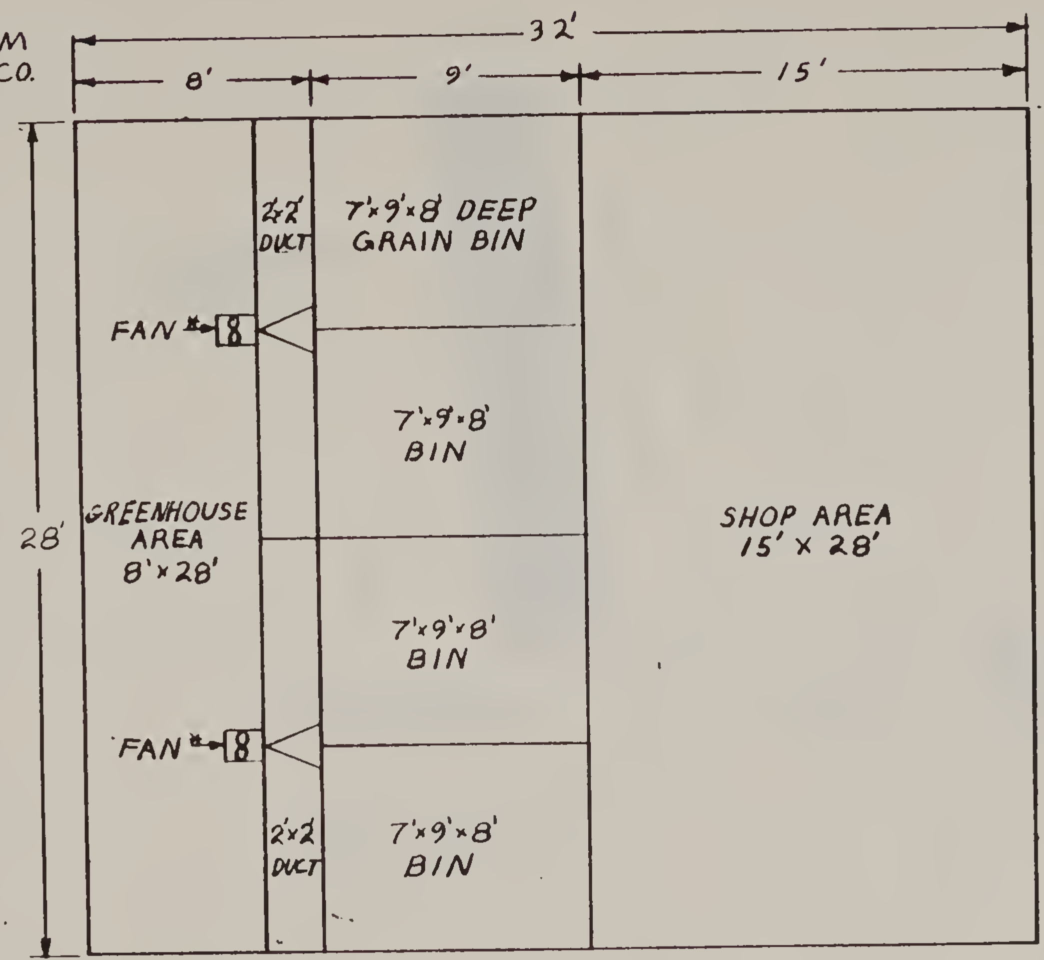
FIG. A-9



STREATER FARM
CHESTERFIELD CO.

FIG. A-10

STREATER FARM
CHESTERFIELD CO.



NOTE: FANS ARE 1 HORSEPOWER
EACH DELIVERS 1900 CFM @ 2" S.P.

FIG. A-11

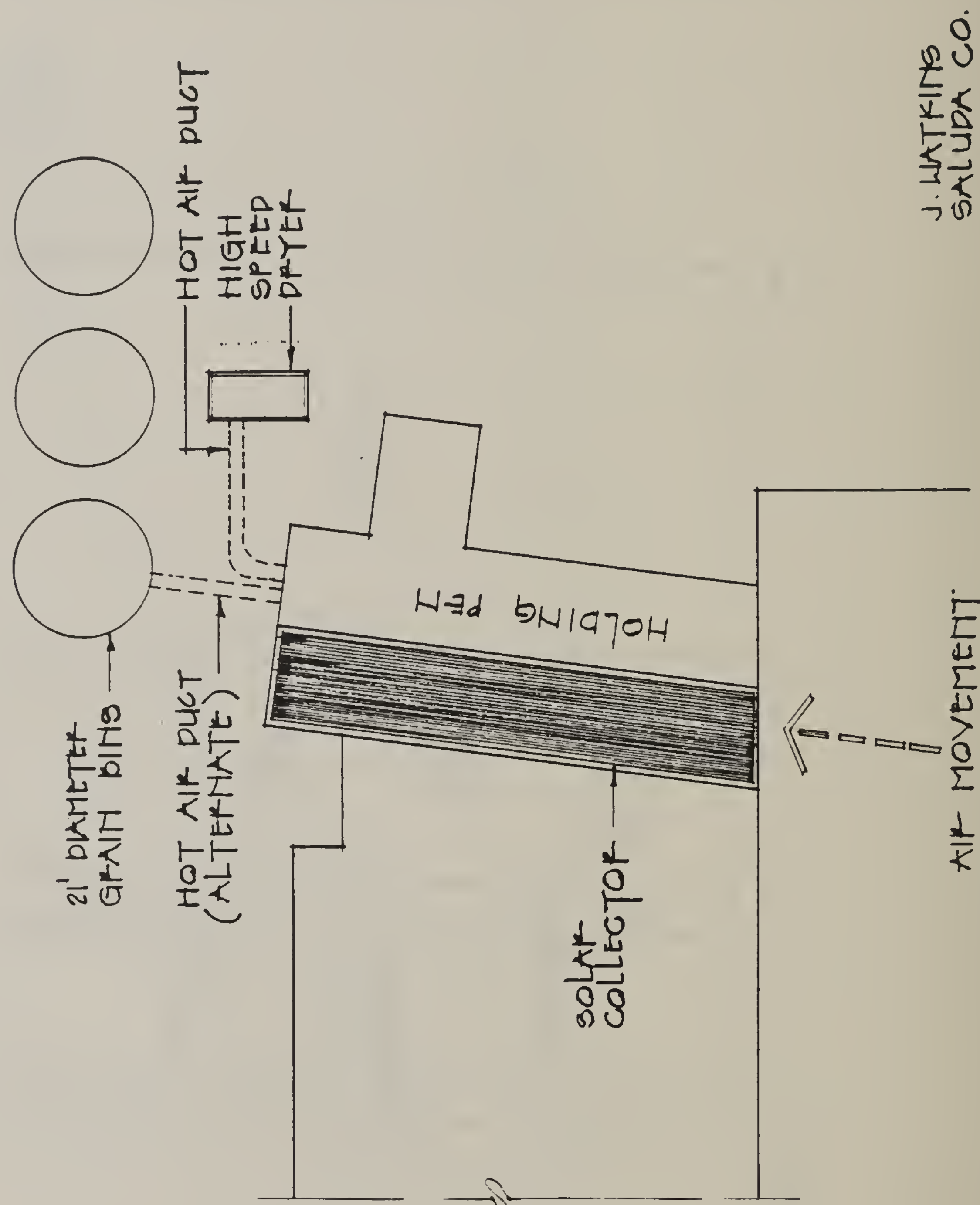

HOT AIR DUCT
HIGH SPEED DRYER
J. WATKINS SALUDA CO.
21' DIAMETER GRAIN BINS
HOT AIR DUCT (ALTERNATE)
HOLDING PEN
SOLAR COLLECTOR
AIR MOVEMENT

FIG. A-12

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245 FINAL REPORT

ON-FARM DEMONSTRATIONS

OF

SOLAR DRYING

OF

CROPS AND GRAINS

University of Tennessee

Institute of Agriculture

Agricultural Extension Service

Agricultural Engineering Department

Knoxville, Tennessee

December, 1982

Project Manager

Kenneth E. DeBusk

Associate Professor

Agricultural Engineering Department

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THE DEMONSTRATION PROJECT

Tennessee is one of nine states selected by the USDA and Department of Energy to set up a demonstration program to show ways solar energy can be put to use in drying farm crops and grain. Demonstrator installations have been built on farms scattered across the state. The farmer-demonstrators are all full-time grain, livestock or dairy farmers ranging in size from small to large. Figure 1 shows the locations of the demonstrations.

OBJECTIVES OF THE PROJECT

1. To demonstrate the technical and economic feasibility of using solar energy technology for drying systems to provide significant amounts of the heating requirements for on-the-farm crop and grain drying and other supplemental uses.
2. To test, to the maximum extent possible, solar energy technology developed under the DOE/USDA SEA federal research program under operating farm conditions.
3. To incorporate and utilize energy conservation techniques well known to the industry.
4. To minimize the interruption or interference in the normal operation of the drying facility.
5. To identify incentives and opportunities for widespread farm applications of solar energy technology.
6. To demonstrate the differences in techniques and feasibility of crop and grain drying in Tennessee. Tennessee is a "mid-latitudinal" state with unique but varying differences in altitude, terrain, and cropping enterprises.

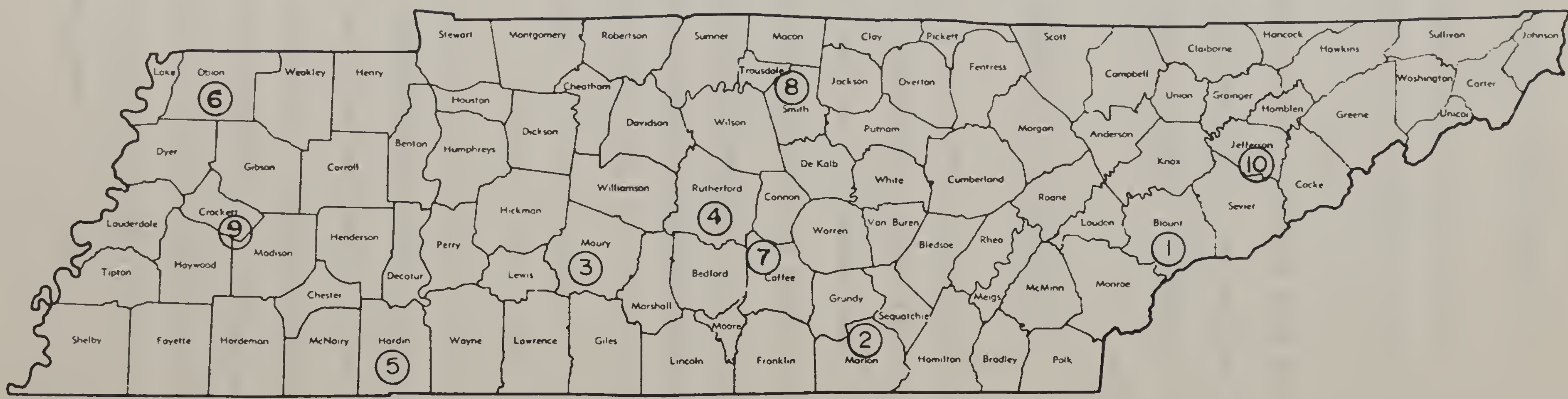

Figure 1. Locations of the demonstrations.

2

7. Emphasize the applicability of solar drying of soybeans as a low-heat drying method for optimizing the production, harvesting, and storage of this crop.
8. As a state with many small corn producers, we feel that we can stimulate more interest in solar drying among these producers who are not so conscious of speed of harvest as are large producers in more northern latitudes.
9. Emphasize the solar drying of large hay bales in demonstrating the improvement of hay quality as developed by the University of Tennessee Agricultural Engineering researchers.

THE DEMONSTRATIONS

Ten demonstration farms are being used to demonstrate five types and variations of solar collectors suitable for drying grains and crops. Multi-purpose use of the collectors which includes drying more than one crop, space heating, and supplementing high capacity systems have been incorporated into each system when possible. The demonstrations are described in more detail in the Description of Demonstrations sections of this proposal. The demonstration types are listed as follows:

* Portable collectors of the modified Illinois type were placed on six farms.
* Wrap-around collectors were retro-fitted to bins on two farms.
* Multi-purpose (hay, wheat, corn, soybean, spaceheating) collectors were constructed on three farms. Designed to incorporate features of Tennessee Research Project Multi-Use Modular Dryer for Large Hay Packages Using Solar Heated Air."

DESCRIPTION OF THE MODIFIED ILLINOIS PORTABLE SOLAR COLLECTOR

This collector has a surface of 288 sq ft (12' diagonal by 24').

The collector (see Figure 2 and Figure 3) utilizes a suspended plate with air flow both below the plate and above - between the plate and the reinforced fiberglas plastic glazing. The plate is 29 ga corrugated metal roofing placed so that air flow is across the corrugations. The plate was painted flat black using PPG oil base metal paint after treating the galvanizing with a surface preparation and applying a base coat of galvanized metal primer paint. All wood surfaces exposed to sunlight were painted flat black.

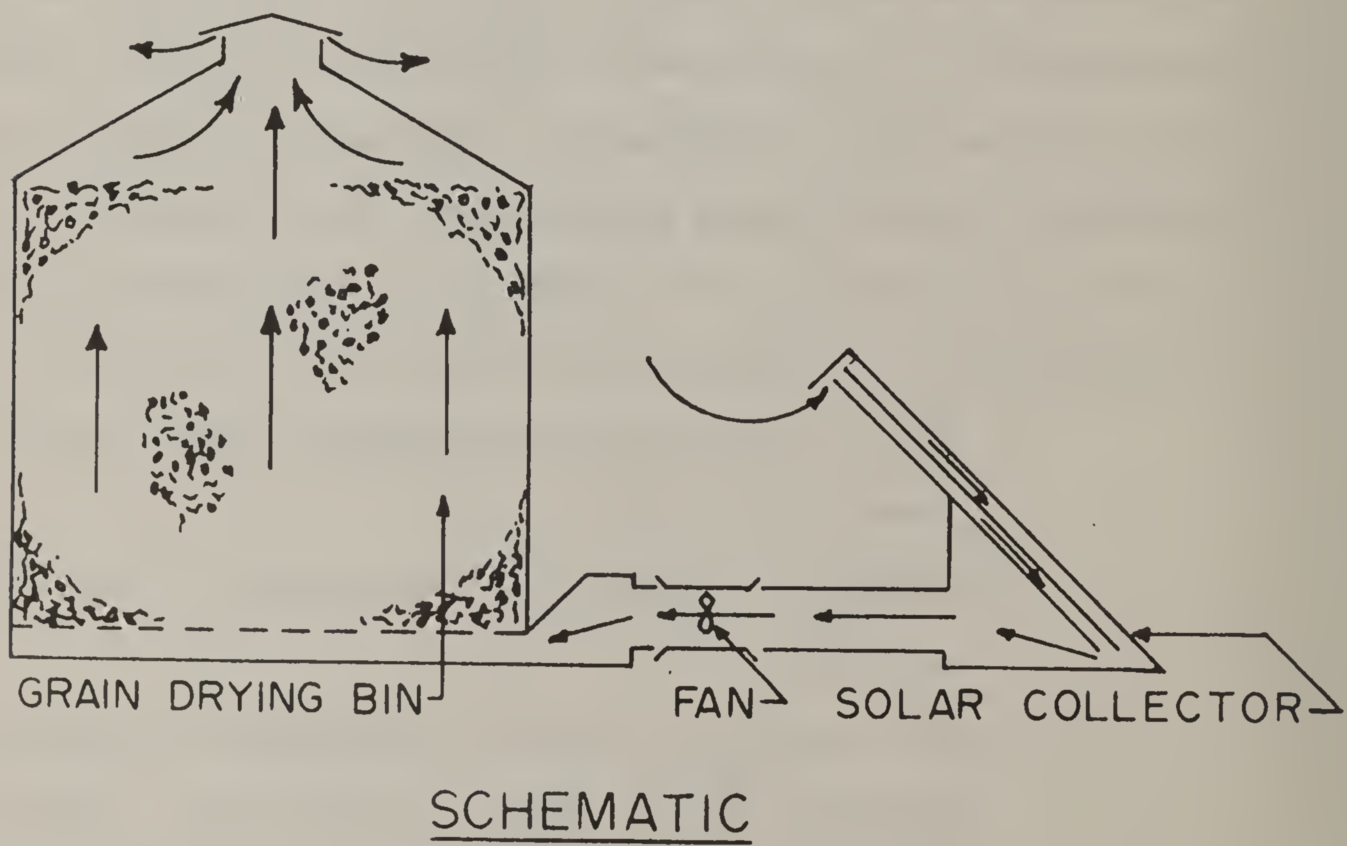

Figure 2. Schematic of the Air Flow Pattern of the Portable Collector.

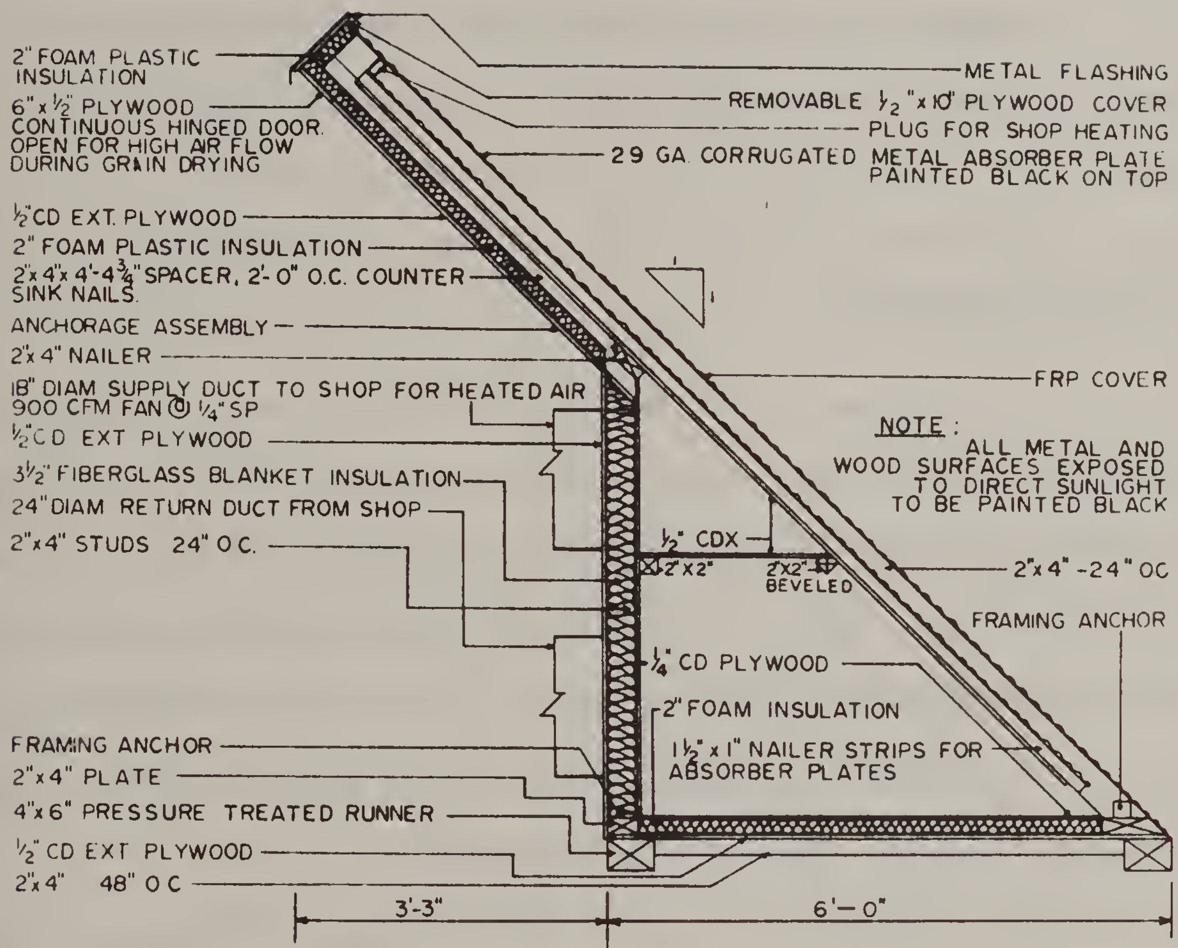

Figure 3. Cross-Section View of the Portable Collector.

The collector glazing is Filon's Solar Plate 15 (Type 546), 4 oz. per square foot weight, with 94% light transmission. The material is guaranteed to maintain at least 81% of its original light transmission for 10 years and remain structurally sound and shatter-resistant for 15 years.

The end walls, the floor and rear overhang were insulated to provide a total "R" value of at least 6. All outside wall surfaces were covered with type CD sheathing grade plywood and painted for weather

resistance. Runners of the collector contacting the ground were constructed of pressure-treated southern yellow pine lumber. Metal flashing was applied to overhanging surfaces to provide capillary run-back protection for the wood.

A diligent effort was maintained in building a structure with the longest possible life considering the relatively inexpensive materials used.

Collector Performance

The efficiency of the modified Illinois portable collector, as determined by the instrumentation system, was within the predicted range. The average daytime efficiency for late Sepember and early October was 55%. Noon (Solar time) efficiency was 58%. These efficiencies were calculated with an air flow of 2.95 cfm per square foot of collector area. Wind velocity effect was not measured but is believed to be insignificant with Tennessee grain drying conditions.

A single-pass air collector used for grain drying would have an expected efficiency much higher than an identical collector used in a recirculating mode. It is believed that air turbulence created by air movement across the corrugations of the absorber plate would account for some of the increased efficiency. No attempt was made to isolate or evaluate this effect.

Air temperature rise through the collector was measured. The average daytime temperature rise for days with daily solar irradiation greater than 1400 Btu/sq. ft. was 29.7° F with air flow of 2.95 cfm/sq. ft. of collector. The average peak temperatures rise (at solar noon) for the same air flow was 54.1° F.

Figure 4 shows the average solar insolation values for the collectors monitored. This figure also gives the air temperature rise for solar time values for this collector.

A common problem in evaluating any air system is the accuracy of air velocity measurement in the duct being monitored. A complete project could be devised on this procedure and we did not have sufficient time to refine this measurement to a fine point. Even though we have some degree of confidence in our velocity measurement, it is recognized that the error could be quite large.

Cost

Materials were purchased by the University of Tennessee for all of the portable collectors used in our program. Obtaining some of the materials; particularily insulation of the type needed and reinforced fiberglas plastic glazing would have been difficult in some of our rural areas. Quantity purchase also resulted in some reduction in cost.

Cost of the materials only are reported, in Table I since most of the labor was supplied by the farmers and University of Tennessee personnel.

Total materials cost was \$808.00 per collector or \$2.80 per ft^2 per collector.

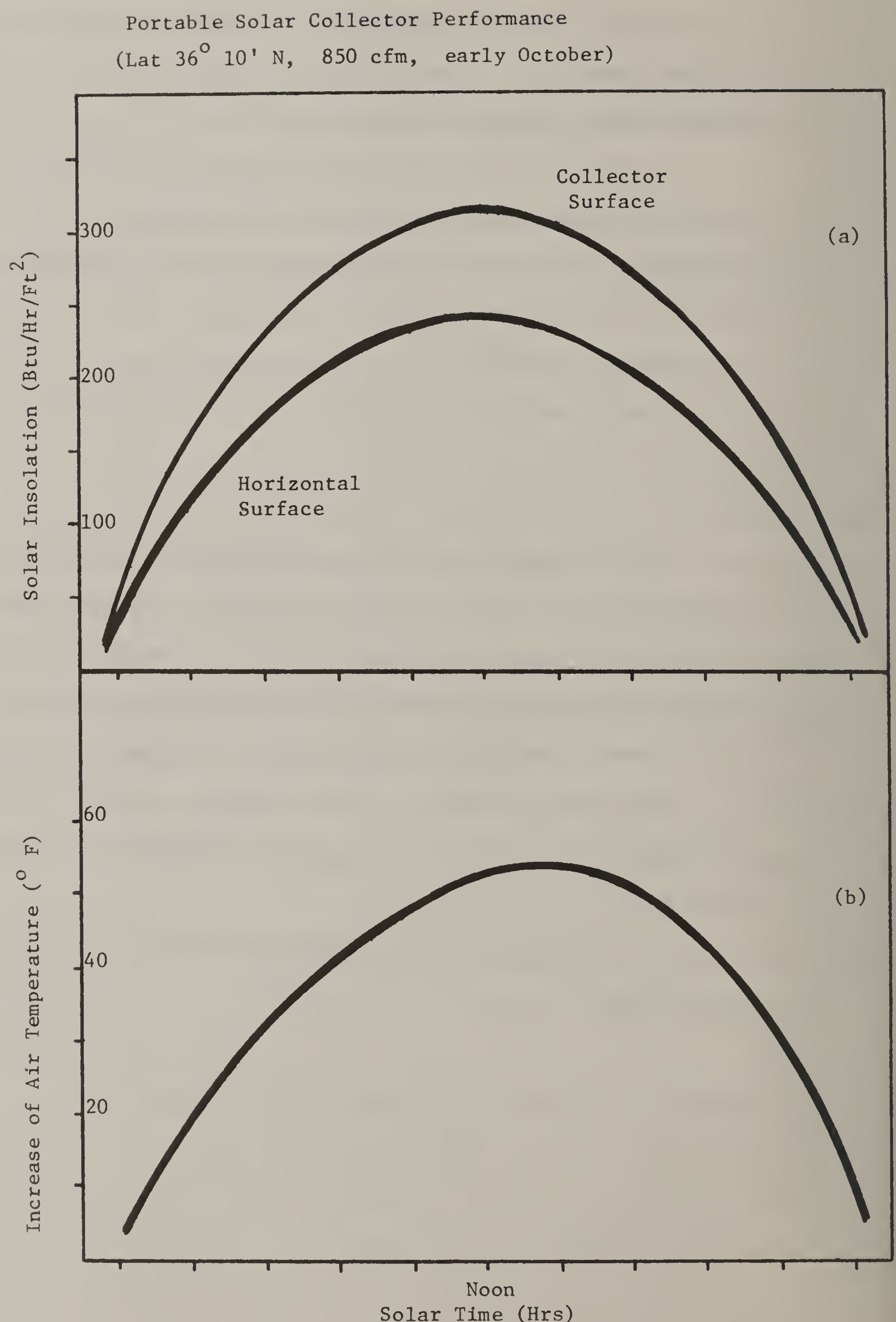

Figure 4. (a) Average insolation values. (b) Temperature rise for a typical day.

Table I. Cost of the Materials

Item	Cost	Percentage of Total Materials Cost
Plywood	$201.00	22.8
Lumber	164.00	20.3
Glazing	148.00	18.3
Absorber Plate	82.00	10.1
Insulation	73.00	9.0
Paint	35.00	4.3
Nails	28.00	3.5
Misc. Hdwe.	77.00	11.7
	$808.00	100.0

Data Collection System

A data acquisition system was developed to allow daily gathering of data via telephone from field units at remote locations. The system consisted of a host unit and five field units. The field units were used to measure temperature, relative humidity, air flow, and solar radiation at collector sites. Measurements were stored in memory as averages for 15-minute intervals. The host unit polled each unit daily, stored the recorded data in disk files, ran diagnostic tests, and initialized the field units for continued data gathering. See Figure 5 for a diagram of the complete data acquisition system.

The field units had sixteen input channels capable of handling inputs from sensors for: temperature, relative humidity, solar radiation,

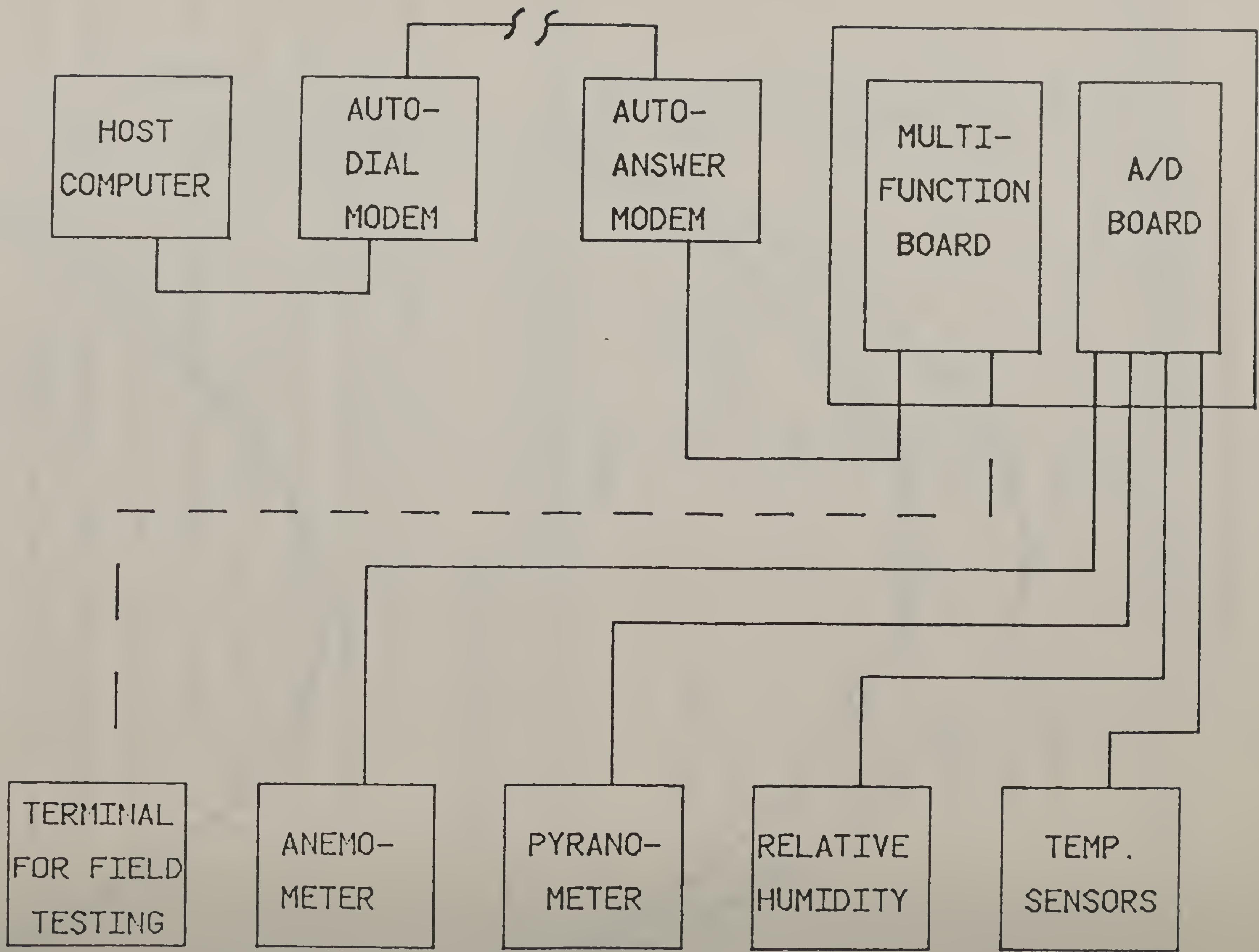

Figure 5. Block diagram of the complete data acquisition system.

and air flow. The units were programmed to read all channels at one-minute intervals, average each measurement over time, and store each 15-minute average. Memory capacity would be adequate to hold at least 24 hours of data. Automatic restart after power failure was necessary.

The host unit was a Digital Equipment Corporation (DEC) LSI-11/2 based computer with dual floppy disk drives for program and data storage. This machine was used for polling the field units, reviewing the data, and transferring data to a larger computer system for analysis. Polling via telephone was accomplished daily during the early morning hours, when long distance rates were lowest. A typical print-out by the (DEC) LSI-11/2 is shown in Figure 6.

```
SI   - SOLAR IRRADIATION ON HOR. SURFACE  [ BTU / (HR-FT-FT) ]
RH   - RELATIVE HUMIDITY  (%)
VEL  - AIR VELOCITY IN DUCTS  (FT/MIN)
TOUT - AIR TEMPERATURE LEAVING COLLECTOR (F)
TABV - AIR TEMPERATURE ABOVE PLATE (F)
TBLW - AIR TEMPERATURE BELOW PLATE (F)
TPLT - TEMPERATURE OF PLATE (F)
TIN  - AIR TEMPERATURE ENTERING COLLECTOR (F)
SPCH - SPARE CHANNELS ON A-D BOARD

FIELD UNIT NUMBER  -  JULIAN DATE  -  EASTERN STANDARD TIME
SI         RH1        RH2        VEL1       VEL2       TOUT       TOUT       TABV
TBLW       TPLT       TIN        TIN        SPCH       SPCH       SPCH       SPCH
Time for FU 5 Is  275 10:59:57
 169.3      65.8        0.0      847.8        0.0      103.6      106.4      105.3
 104.9     120.2       73.3       72.7        0.0        0.0        0.0        0.0
Time for FU 5 Is  275 11:14:57
 181.0      64.6        0.0      868.7        0.0      104.3      107.0      105.4
 104.6     121.8       74.0       73.2        0.0        0.0        0.0        0.0
Time for FU 5 Is  275 11:29:57
 190.6      61.5        0.0      853.5        0.0      106.1      106.0      106.8
 105.1     123.9       74.7       74.0        0.0        0.0        0.0        0.0
Time for FU 5 Is  275 11:44:57
 198.8      61.3        0.0      860.9        0.0      108.5      109.4      110.5
 109.6     126.2       75.3       75.6        0.0        0.0        0.0        0.0
Time for FU 5 Is  275 11:59:57
 205.1      61.6        0.0      848.5        0.0      113.4      114.1      116.5
 118.3     129.7       76.2       75.8        0.0        0.0        0.0        0.0
Time for FU 5 Is  275 12:14:57
 212.8      59.4        0.0      839.6        0.0      115.6      115.0      118.9
 119.4     132.8       77.5       78.3        0.0        0.0        0.0        0.0
Time for FU 5 Is  275 12:29:57
 218.7      58.2        0.0      843.2        0.0      119.2      121.3      119.5
 121.9     128.7       78.1       76.3        0.0        0.0        0.0        0.0
```

Figure 6. Example of printout of the Data Collection System for seven 15-minute time blocks.

Analog Devices AD590 two-terminal IC temperature transducers were used for temperature sensing. These devices provided an output current proportional to the absolute temperature. Precision resistors with a low temperature coefficient were installed in series with the sensor to produce a voltage output.

Relative humidity was measured using Thunder Scientific PC-2101 modules. These modules consisted of a BR-101B humidity sensor and a signal conditioning circuit. Output was typically in the 0.5V to 4V range and was non-linear with relative humidity.

Solar radiation measurements were obtained using Hollis Observatory MR-5 pyranometers. These units had a maximum signal of less than 100 mV.

Velocity measurements were made using thermistor anemometers designed inhouse. The design of these anemometers was patterned after that of Feddes and McQuitty (1980); however, a modification was included to insure automatic temperature compensation of the measurement.

Communications between the host and field units were handled by Hayes Smartmodem units. This 300-baud device had originate and answer capability. Modems were connected to the host and to each field unit. The host unit modem, operating under software control, was instructed to dial field units as desired.

The field units, excluding sensors, were mounted inside inexpensive suitcases. The suitcases had approximate inside dimensions of 6 x 16 x 23 in. adequate for the computer, the modem, terminal boards for input signals, and ventilation equipment. A positive pressure ventilation system, consisting of a small fan and filter mounted inside the suitcase, was provided for cooling. Filtered air drawn in by this fan was exhausted through cable openings and exhaust slots drilled along one edge of the case.

Software

The host unit program was written to permit unattended operation as long as disk space was available for storage of data. (The planned operating procedure was to check the host unit daily except for weekends and holidays.) Execution of one host unit could be started at any time. Once started, the program entered a wait cycle until the "call time" was reached. The computer then "called" the first field unit, received the data, wrote the data and field unit identification on a disk file, checked for field unit errors, terminated the call, and then repeated the procedure for the next field unit. If a field unit did not "answer," the host unit would cycle to the next unit. Any units not contacted during the first cycle were included in a second cycle of calls. After three attempts to call any unit, an error message was written and calling was discontinued for the day. Delays of about 15 minutes were provided before the second and third attempts. These delays were provided to allow for correction of temporary line difficulties.

The host computer created two files for each day's activity. The major file contained the data from each field unit. A log file was created to list all call attempts and any error messages received. In addition to these two files, a printout was provided to summarize the activities and present selected data in summary form for each unit.

The program began execution automatically when power was supplied to the field unit. The system operated in the data gathering mode, scanning all channels at one-minute intervals. At 15-minute intervals, the measurements of each channel for that period were averaged and stored in memory. Data gathering continued even when the field unit was contacted by the host computer.

System Disadvantage: A disadvantage of the system as currently used is the lack of backup in the event of a power failure. Such a failure would cause the loss of all data stored in the field unit memory.

System Advantages: One major advantage of this system is the immediate availability of data. As operated, measurements taken one day were available at the beginning of the next working day. In addition, the host unit can be operated to call field units at any time to verify the current status of the field unit or to check current data. Savings in travel cost are another advantage of this system. Once installed, the diagnostic procedures allow remote verification of proper operation. Sensor problems, once identified, can often be corrected by workers at the field location, eliminating the need for a skilled technician to visit the site. For serious problems, the field unit can be returned for repairs. Accessability of data and cost savings in time and travel are features which make this system desirable for many remote site studies.

DEMONSTRATION 1

The Farm

The John S. Keller farm is located about 2 miles northeast of Maryville. He is a beef producer with a cow-calf operation who grows corn, wheat and soybean - primarily for cash sale. He rents some land and his 450 total acres are scattered as much as six miles from the farmstead. Two thousand bushel of wheat, 5,000 bushel of corn and 10,000 bushel of soybean are average for his production. The 3-bin arrangement at the farmstead is not ideal for placement of the portable collector he is using but with some difficulty he can locate it to get most of the

daily available insolation. Plans are being made to use the collector for farm shop heating and for residential heating.

The Collector Used

One portable collector similar to the design originated by the University of Illinois is being used on this farm, see Figure 2 and Figure 3. Total collector area is 288 square feet. Cost of the collector was $900.00 or $3.13 per square foot.

The Operational Procedure

The collector was connected to one bin at a time then moved to the next bin. An 18 foot diameter, 3,500 bushel bin with a 5 hp fan; 21 foot diameter, 5,000 bushel with a 7 hp fan; and a 24 foot diameter 6,500 bushel bin were utilized in the tests the first year. Corn was placed in layers in the bins and solar heated air was used to assist in the drying of the grain. The experience of the farmer in making decisions in the drying management was relied on completely. A summary of the drying of grain in each bin is shown in Table II.

Table II. Summary of the Performance of Demonstration 1 Collector

Bin	Initial grain moisture	Final moisture	Hours of drying	Gallons of Propane gas used	Calculated value of solar energy used*
#1 (3500 bu)	18%	14.5%		201	$112.00
#2 (5000 bu)	17%	14.5%		186	79.00
			Total		$191.00

*Assumptions & Notes

1. This saving represents the saving in equivalent propane gas at $0.809 per gallon.

2. This grain could have been dried without any supplemental heat if the bins were loaded slowly. A harvest schedule of approximately 2,000 bu. per day was used in filling the bins.

3. The saving was a real one, compared to Mr. Kellers practices in dring grain.

DEMONSTRATION 2

The Farm

The Hill and Garner Dairy Farm is located 2 miles north of Whitewell on Highway 27. This partnership farm has a milking herd of 200 cows and grows approximately 20,000 bushesl of corn. A modern calf barn uses a sizable amount of heat energy and the collectors will be used to assist in heating it. Arrangement of the bins creates a problem in locating the collectors for best orientation. Most of the corn is dried in one bin in batches and transferred to other bins for storage. The heat demand for grain drying is high for this farm and the drying period is short but economic justification for the collectors will be realized through their use for calf barn heating.

The Collector Used

Two of the modified Illinois type portable collectors are in use on this farm (see Figure 2 and Figure 3). Total collector area is 576 square feet. Total cost of the two collectors was $1,800 or $3.12 per square foot.

The Operational Procedure

The two collectors were placed in the best positions possible for the bin arrangement. The collectors operated when corn was being dried. Due to the limited number of field data collection units we had available (5) the system could not be monitored in the fall of 1982. We had expected to monitor these collectors in the fall of 1983. The bin arrangement for this farm consists of a 36 ft. diameter batch-in-bin dryer with provision to transfer to storage bins. All grain is dried in the batch-in-bin dryer. Natural gas is used for drying.

A summary of the drying schedule and energy utilized is shown in Table III.

Table III. Summary of the Performance of the Hill and Garner Collectors

Batch No.	Initial Moisture %	Final Moisture %	Natural gas used (cu. ft.)	Calculated value of solar energy used (cu. ft.) of natural gas
1 (2500 bu)	29	14.5		
2 (4700 bu)	20.4	14.5		
3 (1600 bu)	18.2	14.6		
Totals 8800 bu	(Weighted moisture emoval 6.64%)		23,900	83,636 ($565.00)
4 (700 bu)	16.9	14.6	none	undetermined
5 (6200 bu)	15.9	14.6	none	undetermined
6 (1600 bu)	15.2	14.6	none	undetermined

DEMONSTRATION 3

The Farm

The James Lockridge farm located near Spring Hill, produces 475 acres of soybeans, wheat and 25 acres of corn. An avid conservationist, Mr. Lockridge sows all of his land to a wheat cover crop. Some of the wheat is turned in spring for early soybean planting and a portion is harvested. Double-crop soybeans are reseeded for the harvested portion. The proportion that is double cropped depends on management factors.

In addition to the row-crops, Lockridge keeps approximately 60 brood cows in his cow-calf operation.

The need for heated-air drying on this farm is not high but solar collectors can provide enough supplemental heat for soybean and wheat drying.

The Collectors Used

Two of the modified Illinois type portable collectors are in use on this farm, see Figure 2 and Figure 3. Total collector area is 576 square feet. Total cost of the two collectors is $1,800.00. Cost per square foot was $3.12.

The Operational Procedure

The bin arrangement and orientation was very poor for locating the collectors. The collectors had to be placed on the north side of the bins far enough away to avoid shading. Duct lengths of 20 to 65 feet were necessary to reach the four bins. Due to the limited number of field data collection units we had available (5) the system could not be monitored

in the fall of 1982. We had expected to monitor these systems in the fall of 1983. Log sheets were kept by the farmers and their report is submitted in Table IV.

Table IV. Summary of the Performance of the Lockridge Collectors

Date	Bin No. and Diameter	Bushels Added	Moisture %	Final Moisture	Type of Grain Dried
10-14-81	#1 (24 ft)	800	14.2	12.4	Soybean
10-15-81	#1 (24 ft)	750	13.6	11.6	Soybean
10-17-81	#1 (24 ft)	925	13.2	11.4	Soybean
10-20-81	#1 (24 ft)	1,110	12.9	11.5	Soybean
10-21-81	#1 (24 ft)	875	13.7	11.4	Soybean
10-22-81	#1 (24 ft)	1,240	13.8	11.2	Soybean
07-17-82	#1 (24 ft)	910	14.2	12.6	Wheat
07-18-82	#1 (24 ft)	1,050	13.9	12.1	Wheat
07-19-82	#1 (24 ft)	455	14.6	11.9	Wheat
10-14-82	#2 (12 ft)	620	14.3	12.0	Soybean
10-15-82	#2 (12 ft)	540	14.1	12.0	Soybean
10-16-82	#3 (14 ft)	480	13.8	12.0	Soybean
10-17-82	#3 (14 ft)	840	13.2	12.0	Soybean
10-17-82	#3 (14 ft)	910	13.4	12.0	Soybean
10-20-82	#3 (14 ft)	350	12.6	12.0	Soybean
	Total	11,855			

DEMONSTRATION 4

The Farm

The John L. Batey, Jr. farm is located on Browns Chapel Road about 8 miles northwest of Murfreesboro. This 400 acre farm contains soybeans, corn and wheat. A swine finishing operation consumes all of the corn grown on the farm. A new 6,500 bushel bin was needed and it was located ideally for connection to the collector. Only three feet of duct was necessary from collector to the bin drying fan.

The Collector Used

One portable collector of the modified Illinois design was used on this farm. See Figure 2 and Figure 3. Collector area is 288 square feet. Cost of the collector was $900.00 or $3.12 per square foot.

The Operational Procedure

The new 6,500 bushel bin was located so that it could be used as a batch-in-bin drier for transfer of dried grain to other storage bins. However only one filling of the 6,500 bushel bin was made in 1982.

The bin was completely filled and dried in layers of corn ranging from 2 to 7 feet. The initial 20% moisture corn was almost ideal for supplemental heated air drying in Tennessee. Drying of the corn to 13% was accomplished in 22 days and no other type of fuel was required.

DEMONSTRATION 5

The Farm

Edwin Willoughby farms 2,000 acres in Hardin County on the Tennessee River. He grows about 400 acres of corn and 1,600 acres of soybeans. Some of the soybean acreage is double cropped with wheat. He has storage for 80,000 bushel of grain. In an operation of this size, speed of drying is important and an extremely large collector area would be required for a significant impact on total drying energy needs. It was decided that the three portable collectors used would be connected to a fan serving two of the 9,000 bushel bins. A wye transition allows drying in either or both of these bins with the same fan.

The Collectors Used

Three portable collectors of the modified Illinois type were used, see Figure 2 and Figure 3 for collector details. Total area of the collectors is 864 square feet. Total cost of the 3 collectors was \$2,700.00. Cost per square foot of collector was \$3.12.

The Operational Procedure

With the bin arrangement that existed prior to use of the solar collector units, it was necessary to locate the collectors on the north side of the bins. It was also necessary to move away from the bins approximately 40 feet to avoid shading. Since 3 collectors were used the duct to the drying fan was connected as the vertical leg of a T from which two collectors were connected in series in one direction and the third collector in the opposite direction of the top of the T. Inlets to the

collectors were adjusted to cause equal air movement over each collector. Table V shows the performance of the collector.

Table V. Summary of the Performance of the Willoughby Collectors

Batch No.	Type of Grain	Initial Moisture %	Final Moisture %	LP gas Used	Calculated value of solar energy Used
1 (2264 bu)	Soybeans	17	12	None	$182.00
2 (2264 bu)	Soybeans	18	12	None	219.00
3 (2264 bu)	Soybeans	17	12	None	182.00
4 (1078 bu)	Corn	19	15	None	70.00
5 (1083 bu)	Corn	18	15	$40.00	13.00
6 (1549 bu)	Corn	18	15	None	75.00
7 (2264 bu)	Soybeans	15	12	None	110.00
8 (2264 bu)	Soybeans	14	12	None	73.00
9 (2264 bu)	Soybeans	15	12	None	110.00
10 (2264 bu)	Soybeans	15	12	None	110.00
11 (2264 bu)	Soybeans	15	12	None	110.00
12 (2264 bu)	Soybeans	15	12	None	110.00
13 (2264 bu)	Soybeans	15	12	None	110.00
Totals 22,640 bu.				$40.00	$1,474.00

DEMONSTRATION 6

The Farm

The Charles Hutchinson farm in Obion County 6 miles northeast of Union City is a grain farm. Mr. Hutchinson grows 300 acres of corn and 500 acres of soybeans. One hundred fifty acres of the soybeans are planted as a double crop after wheat. He has 6 bins with combined storage of 35,000 bushels.

The Collectors Used

One portable collector of the modified Illinois design, (see Figure 1 and Figure 2) and one wrap-around collector (see Figure 6) are in use on this farm. Total area of the portable collector is 288 square feet and total area of the wrap-around collector is 1,077 square feet. Cost of the portable collector was $900.00. The wrap-around collector cost was $1,673.00. For this collector the cost per square foot of effective collector area was $3.97 while the cost per square foot of total area was $1.55.

A 25 foot diameter by 17'-0" (eve) height bin was available for installation of a wrap-around collector, see Figure 7(b) and 7(c). A small amount of shading was to be expected due to closeness of an adjacent bin. The drying fan for this bin was already located about mid-way of the northwest quadrant of the bin and it was not deemed feasible to relocate it. For this reason the inlet for the collector is located in the northeast quadrant and air is pulled horizontally the entire 60 feet of the collector length. Figure 7(a) shows the cross section detail of the collector.

The Operational Procedure

The installation of the wrap-around collector was not completed in time for the bin to be filled in layers. It was completely filled with 18% moisture corn and drying was started. A grain stirrer aided in overcoming possible difficulties. The procedure used in 1982 was not a realistic test for this collector. It is hoped that further testing for this collector can be continued in 1983.

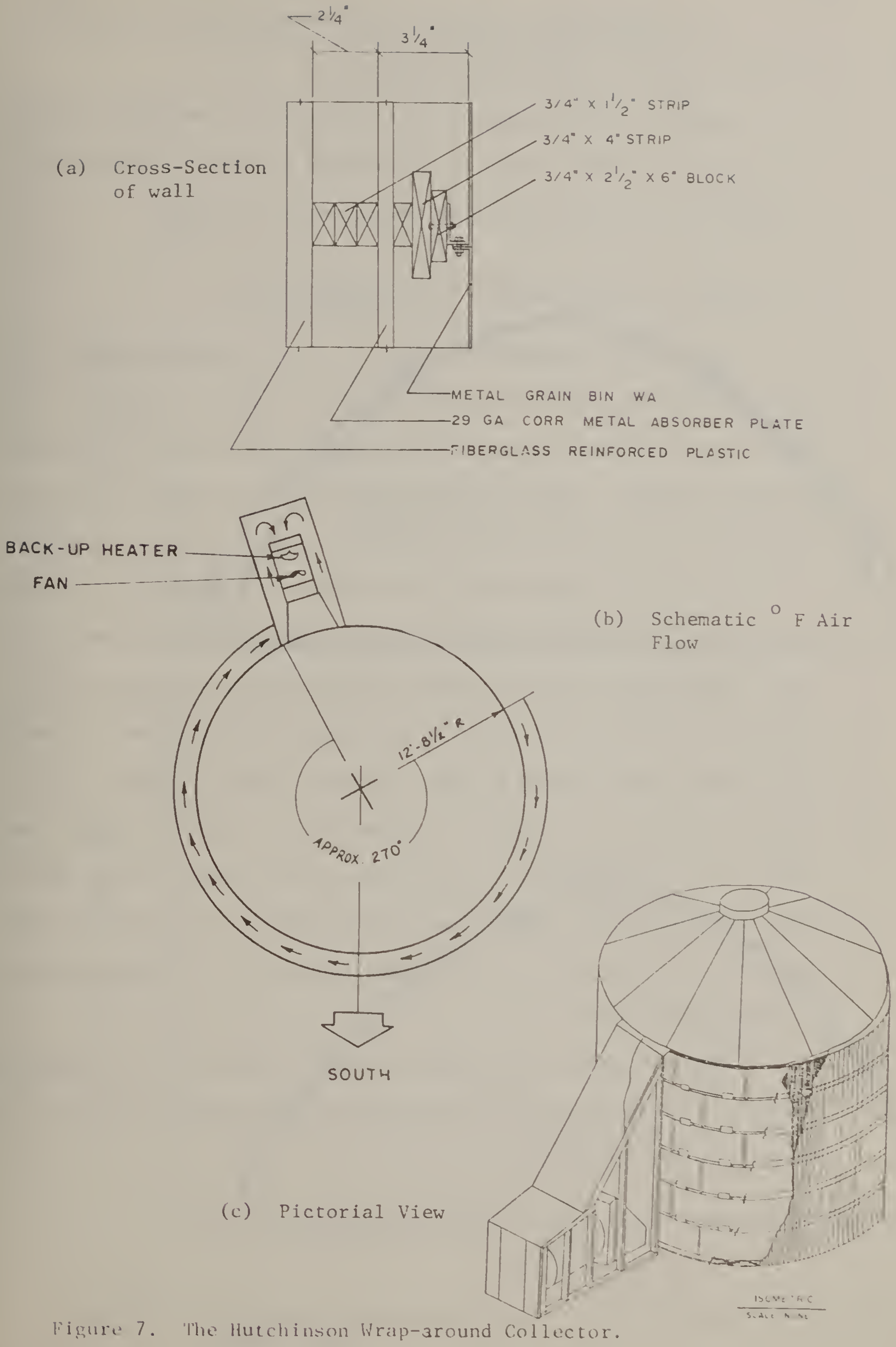

Figure 7. The Hutchinson Wrap-around Collector.

Six thousand bushels of corn were dried from 18% to 14.5% in 336 hours with the wrap-around collector.

Since Mr. Hutchinson has very limited labor available, use of the portable collector was not accomplished in 1982. Fabrication of a connecting duct appeared to be the principal problem.

Performance of the Hutchinson Wrap-Around Collector

The average daytime efficiency of this collector was 65%, based on the effective area of the collector (bin diameter x collector height). Air flow at this efficiency was 18.5 cfm per square foot of effective collector surface. Wind velocity effect was not measured but is believed to be insignificant with Tennessee grain drying conditions.

Average air temperature rise through the collector for a solar day was 3.9° F while the peak solar noon temperature rise was 7.2° F. These temperature rises were taken at the exit side of the collector before air entered the fan and do not include fan motor heat. Pressure drop across the collector was kept below 0.2 inches of water. Insufficient time was available to adjust the air flow for higher temperature rise. Air velocities at the inlet of the collector were fairly uniform, top to bottom. Higher temperature rise would be possible with lower air flow but this is unimportant since all of the heat collected is being delivered.

Figure 8 shows the average insolation values for the wrap-around collector. This figure also gives the air temperature rise at solar time values for this collector.

Wrap-Around Solar Collector Performance
(Lat 36^{o} 30' N, 8100 cfm, late October)

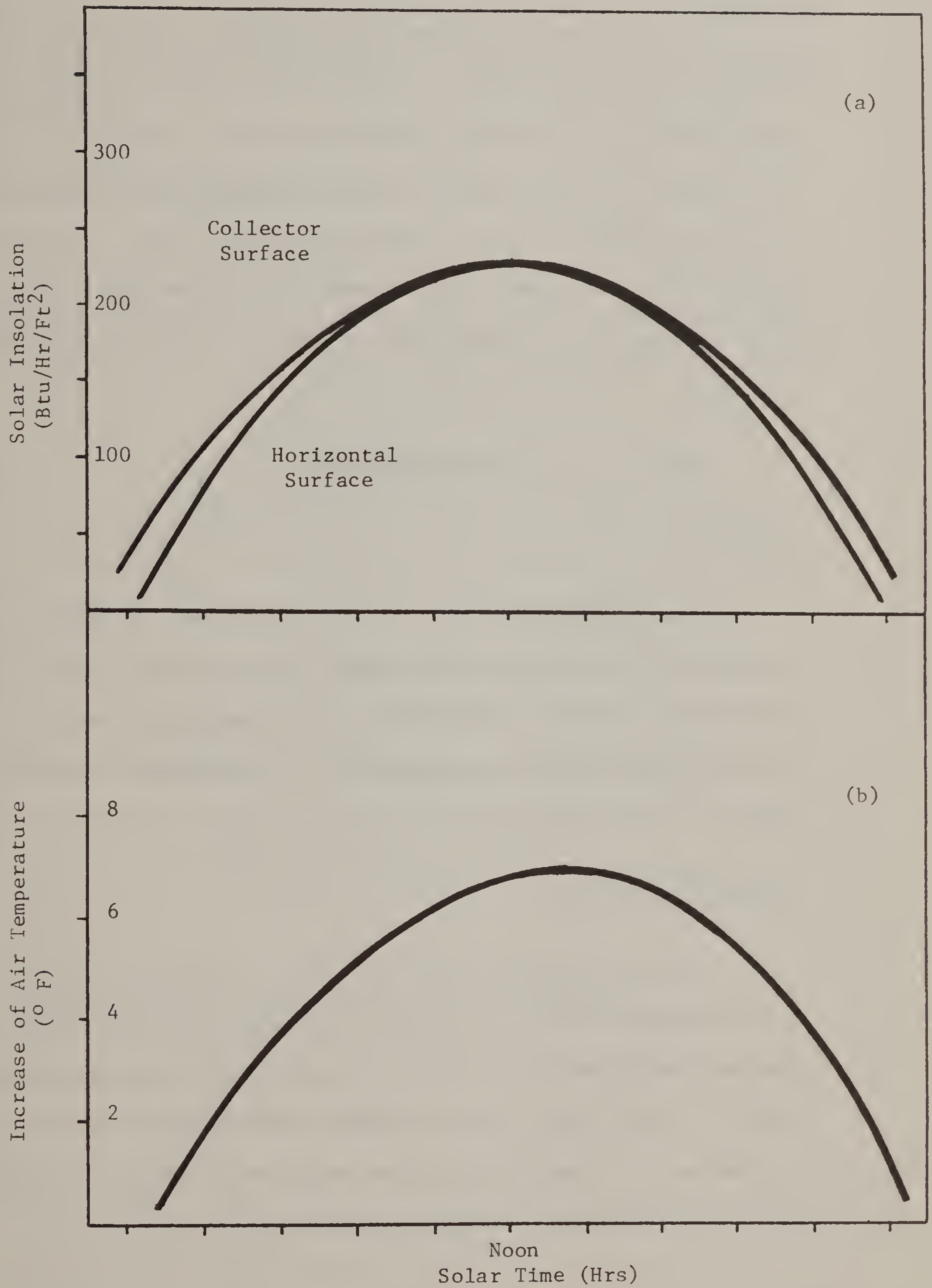

Figure 8. (a) Average Insolation Values. (b) Temperature Rise for a Typical Day.

Data Collection System

A data collection system was developed to allow daily gathering of data via telephone from the unit at the Hutchinson Farm. The host unit a DEC LSI-11/2 located in the Agricultural Engineering Department polled the field unit daily to transfer t4emperature, relative humidity, air flow and solar radiation data from field to host. A detailed description of the hardware and software used in data collection can be found in the Portable Solar Collector section of this report beginning on page 9.

DEMONSTRATION 7

The Farm

Austin Anderson farms 1,300 acres in Coffee County near Manchester, 650 acres of which are for row crops. He grows nearly 350 acres of corn, and double crops 300 acres of wheat and soybeans most years. A cow-calf operation with 250 brook cows makes up the other major enterprise of the farm.

The Collectors Used

Mr. Anderson has several bins but was interested in retro-fitting a wrap-around collector to a 30 foot diameter by 16 foot height bin that had good exposure to the south. Like the Hutchinson farm situation the fan for the bin was located northwest of the center of the bin and it was necessary to move the collector air from northeast to northwest around the southern two-thirds of the bin wall.

The collector area totalled 1,149 square feet with an effective area of 492 square feet. Total cost of the collector was $2,561.00. Cost per square foot of effective and total area was $5.20 and $2.23 respectively.

The Operational Procedure

Corn was added in layers to a total depth of 10 feet (3,142 bushels) in layers on October 10, 1981. Initial moisture of the grain was 22% and it was successfully dried to 13% moisture with the use of 30 gallons of propane gas.

Wheat was placed in the bin beginning June 25, 1982 to a depth of 10 feet (3,142 bushels) over a period of 3 days. Initial moisture of the grain was 20%. It was successfully dried to 13% and stored until September 15. No propane gas was used.

Corn was placed in the bin beginning October 10, 1982 to a depth of 14 feet (4,398 bushels) on a fill schedule of four feet per day. Initial moisture content was 23% and final moisture was 15.5%. The fan was operated on sunny days and the corn was successfully dried without the use of propane gas. The corn was moved from the bin after about 4 weeks.

Performance of the Anderson Wrap-Around Collector

Since only five field instrumentation units were available, this system was not monitored in 1982.

The efficiency of the Anderson collector was expected to be similar to the Hutchinson wrap-around collector. This efficiency is expected to be approximately 65% for daytime use.

It is estimated that a total of 84 million Btu of energy has been collected and utilized to date by this collector. This represents \$739.00 in terms of equivalent propane gas. A summary of the drying schedule and energy utilized is shown in Table VI.

Table VI. Performance of the Anderson Wrap-Around Collector

Type of Grain	Date	Bushels	Initial Moisture %	Final Moisture %	Propane Used	Calculated value of solar energy used
Corn	10-01-81	3,142	22	13	\$21.00	\$230.00
Wheat	06-25-82	3,142	20	14	None	153.00
Corn	10-10-82	4,398	23	15.5	None	356.00
Totals		10,682	(7.45% weighted average)		\$21.00	\$739.00

THE MULTI-PURPOSE DRYER FOR

LARGE HAY BALES USING SOLAR HEATED AIR

The purpose of this dryer is to provide a practical and economical structure to use low-temperature, solar-heated air to dry large round bales of hay, to dry shelled corn and for supplemental space heating of a utility or shop area during the winter months. The design is based on the work of Dr. Bobby L. Bledsoe of the University of Tennessee Agricultural Engineering Department in recent years under the USDA/SEA Solar Energy Systems for Agricultural Programs.

The units used in this project were of different size than the Bledsoe unit but design parameters were similar. Two of the units, the

Manley unit and the Spence unit, were designed to dry 24 large bales simultaneously. See Figure 8 and Figure 9 for details of the multi-purpose collectors on the Manley and Spence Farms. The Key collector, a retro-fitted unit, accommodates 14 large bales simultaneously. The sections of this report for each of these farms will relate this dryer to each situation.

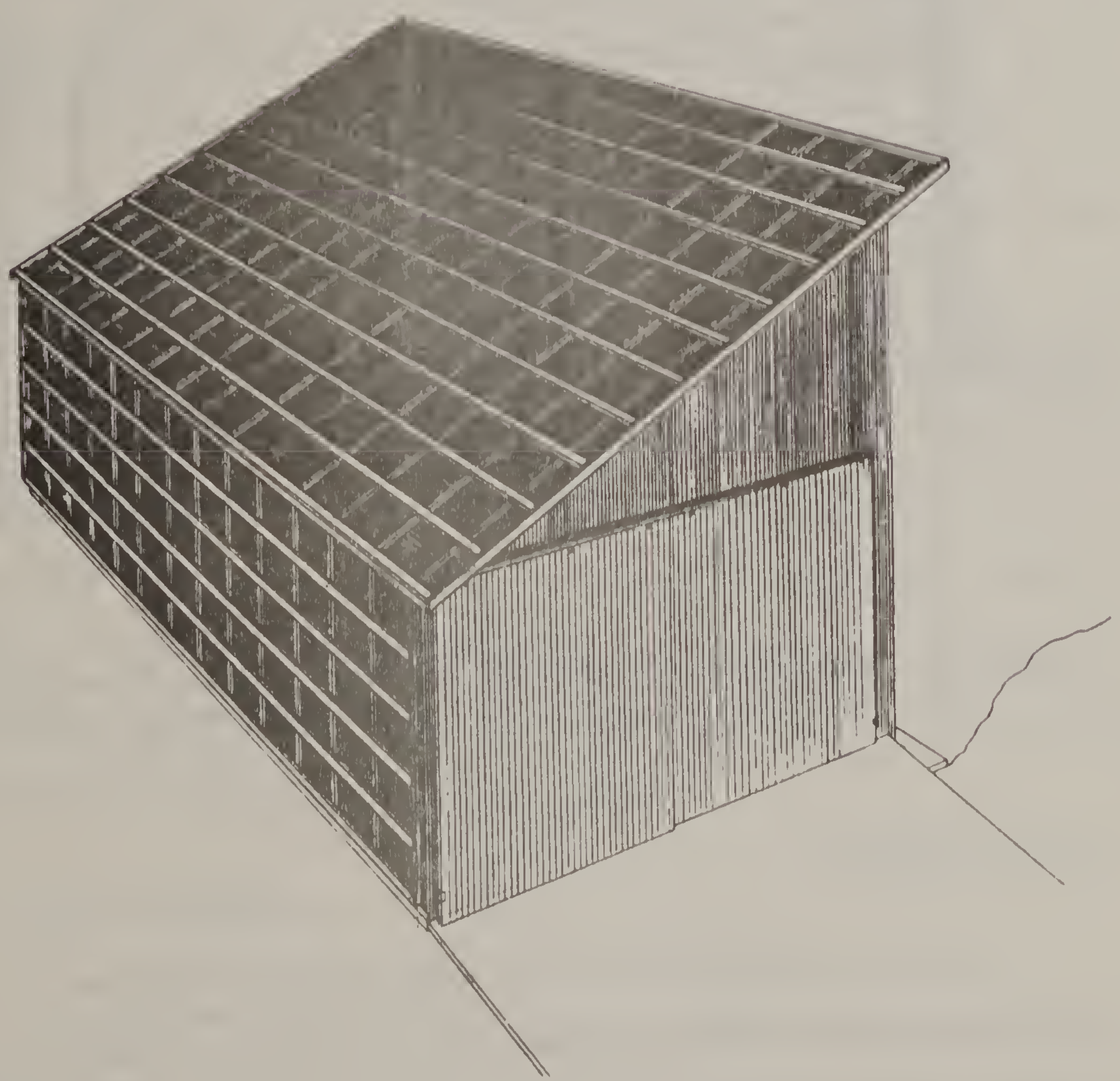

Figure 9. Pictorial view of the Multi-Purpose Hay, Grain and Shop Units in use on the Manley and Spence Farms.

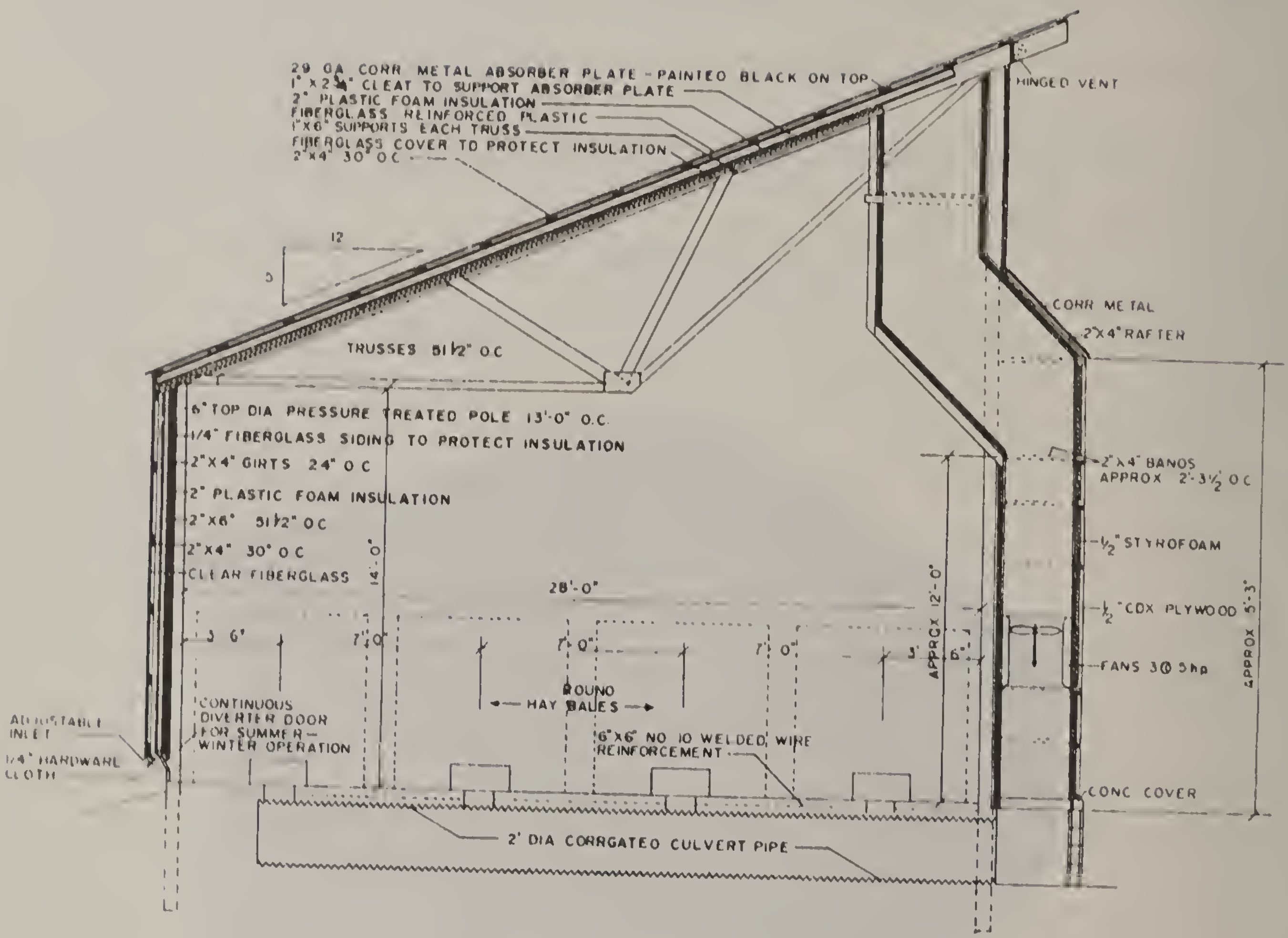

Figure 10. Cross-section view of the Multi-Purpose Hay, Grain Drying and Shop Collector in use on the Spence and Manley Farms.

The Air System

The air handling units for these dryers were Vane-axial crop drying fans. Fan units were sized to provide all bales with 400 cfm per bale at 4 in. water pressure. The systems were designed so that the fans could also be used to supply solar heated air to grain bins adjacent to the structure. Two systems (Spence and Manley) have three five horsepower fans each and one system (Key) has two five horsepower fans. It is possible, when desired, to divert larger amounts of air to fewer bales

if some floor duct openings are closed. This offers flexibility when the entire system cannot be loaded with bales or when greater air flow per bale is desired. Reasons for greater air flow might include having wetter than desired bales or more dense than desired bales.

The south wall and entire roof area of the monoslope, pole barn design, dryer building serves as a solar air heater during the day. Air enters the south wall one foot above ground level. Suction of the fans provides the inertia for air movement. The air travels up the south wall through the collector to the eave of the building where continuous passages are connected to the roof section. It continues up the roof to the highest point of the monoslope where it is collected by a manifold duct which runs the length of the building. This manifold feeds a vertical duct which connects to the bank of fans. The fans are mounted for vertical air movement and they deliver air downward into the under-floor manifold duct. This manifold feeds the lateral under-floor ducts on which the bales are set. The air continues through the duct to openings under each bale. Twelve gage, metal sealing rings, 2 feet in diameter by 10 inches high, set over the floor openings. The bales are set on end over the sealing rings and pressed down on the rings with the tractor front end mounted spearing device.

The Collector Design

A suspended plate collector with single glazing was used. This collector was constructed between trusses placed on 49-½ inch centers so that 4 foot dimension rigid insulation would fit between the trusses without trimming. Rigid expanded bead polystyrene insulation, 1-½ inches thick provided the heat barrier on the building side of the collector.

Operational Procedure

The alfalfa is cut at the early bloom stage. Typically, mowing is begun at 1:00 p.m. and continued through the rest of the day. Some mowing is usually required on the second day to provide enough hay for the 24 bale units. Windrowing of the hay is usually begun when the dew dries on the third day. Windrowing is completed by early afternoon. With this schedule hay has typically dried to about 40 percent moisture when windrowing is begun. Baling of the hay is begun in early afternoon of the third day when the moisture content is approximately 35 percent. The hay is removed from the field to the solar dryer and placed on the dryer within 2 to 3 hours after baling.

Drying is started immediately and the fans are allowed to run until early evening. The fans should usually be operated intermittently the first night - enough to prevent the hay from heating. Unless relative humidity is excessively high, 85% or higher, the fans are allowed to run all of the next day. If drying and solar conditions are good, the fans are not run at all the second night (after drying is begun). The fans are operated the next day, and, if weather conditions have been good, drying will be completed during the third day from initiation of drying. The hay is considered to be dry enough for safe storage when the moisture content of the wettest portion of the bale is 20 to 22 percent. The last part of the bale to dry will be the upper, outer ring of the bale.

Under the best conditions encountered, alfalfa hay was dried on these units within 50 hours after it was placed on the dryer. The average total (night and day) drying time was approximately 65 hours. During prolonged rainy periods hay stayed on the dryer as much as 8 days. The

fans were not operated all of this time - only periodically when drying conditions were poor-to prevent serious overheating of the hay.

Performance of the Collector

The collector performed at an average day time efficiency of 49%. Peak of efficiency at solar noon was 53%. Air flow per square foot of collector was 8.73.

Temperature rise through the collector was measured. The average daytime temperature rise for days with daily solar irradiation greater than 1300 Btu/square foot (horizontal) was 9.8° F with air flow of 8.73 Btu per square foot.

The average peak temperature rise (at solar noon) for the same air flow was 15.0° F.

Figure 11 shows the average solar insolation values for the collector monitored. This figure also gives the air temperature rise at solar time values for this collector.

Efficiency of the collector was slightly below the expected level. Efficiency was calculated based on the total roof and south wall areas. If only the roof area was used for calculation, efficiency would be much higher. It is repeated that the accuracy of the air velocity measurement could be the source of considerable error. Quite possibly the efficiency is actually higher than the monitored value.

Data Collection System

Only one of the collectors of the multi-purpose type was monitored in 1982. The data acquisition system used for this collector was a part of the overall system used in this project. The system is explained in the Portable Collector section of this report beginning on page 9.

Multi-Purpose Solar Collector Performance

(Lat 30° 11'N, 16,300 cfm, early October)

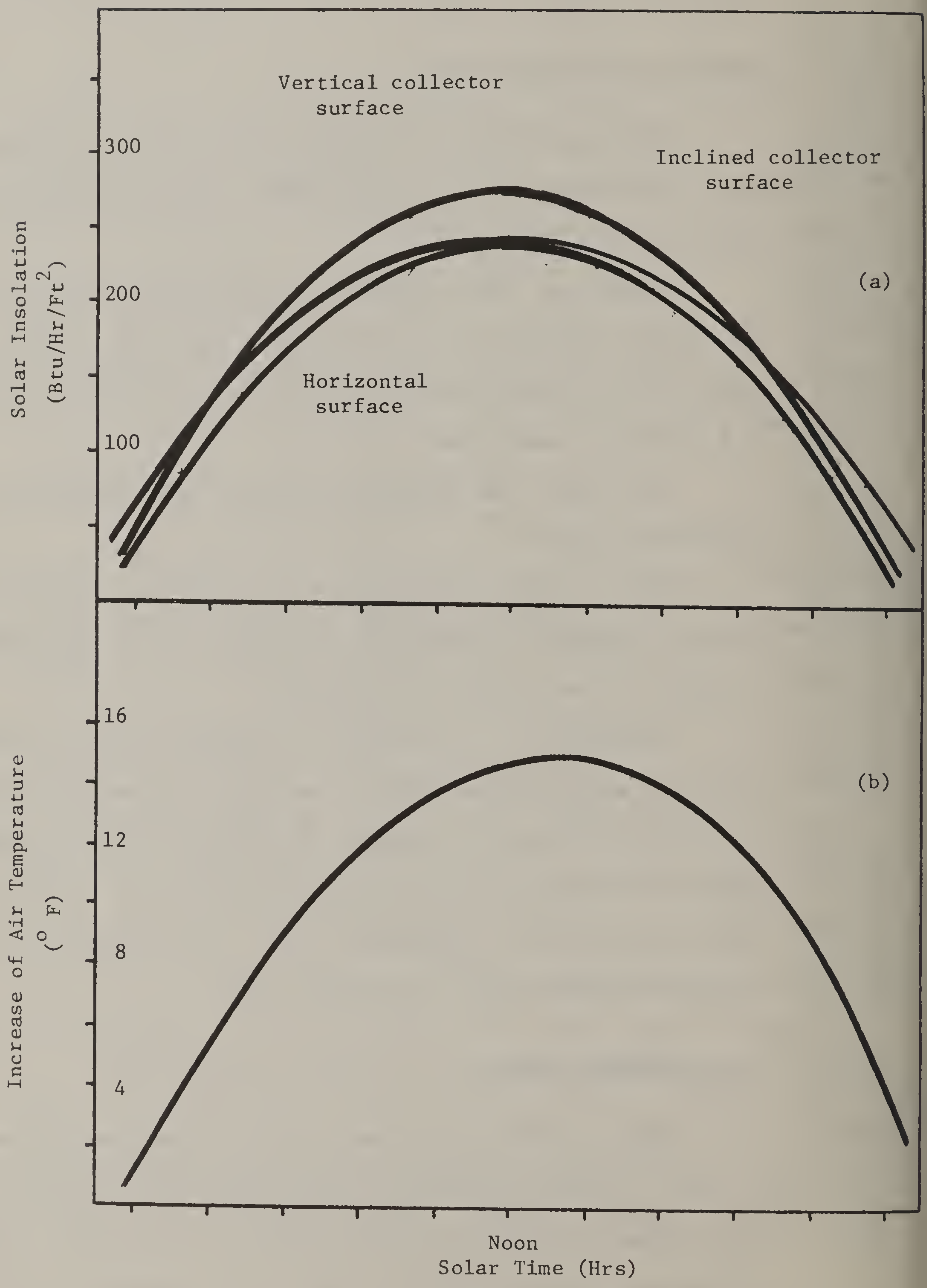

Figure 11. (a) Average Insolation Values. (b) Temperature Rise for a Typical Day.

DEMONSTRATION 8

The Farm

The Sam Key, Jr. farm is located approximately six miles east of Carthage. Mr. Key farms 217 acres, keeps 65 brood cows, raises hogs and grows 2 acres of burley tobacco. He bales about 120 large bales of hay each year for the cow-calf enterprise. In 1980 he constructed a 14'w x 42'L x 18' sidewall shed on the south side of an existing tobacco barn. This is not a row crop farm but the possibilities for using solar energy for hay drying, burley tobacco supplemental drying, and space heating warranted the decision to sue this farm as a demonstration.

The Collector Used

A multi-use dryer (see Figure 12) using solar heated air has been constructed. The 14'w x 42'L x 18'h shed would accomodate space for a 14 bale hay dryi ng unit. Seven lateral ducts of 2 foot diameter corrugated culvert pipe were installed before pouring the 6 inch thick reinforced concrete floor. Each duct accommodated two bales of hay and was connected to a manifold duct located below ground level in the adjacent tobacco barn. Figure 13 shows a pictorial view of the unit.

Two, five horsepower Bulter model 2,450 fans supplied solar heated air from the collector to the manifold duct. A diverter/damper system was incorporated to provide the option of diverting solar heated air into the adjacent tobacco barn to aid burley curing during abnormal periods.

Total cost of the Key multi-purpose collector was $7,143.00 for a collector area of 1,120 square feet (roof plus side wall). Total cost

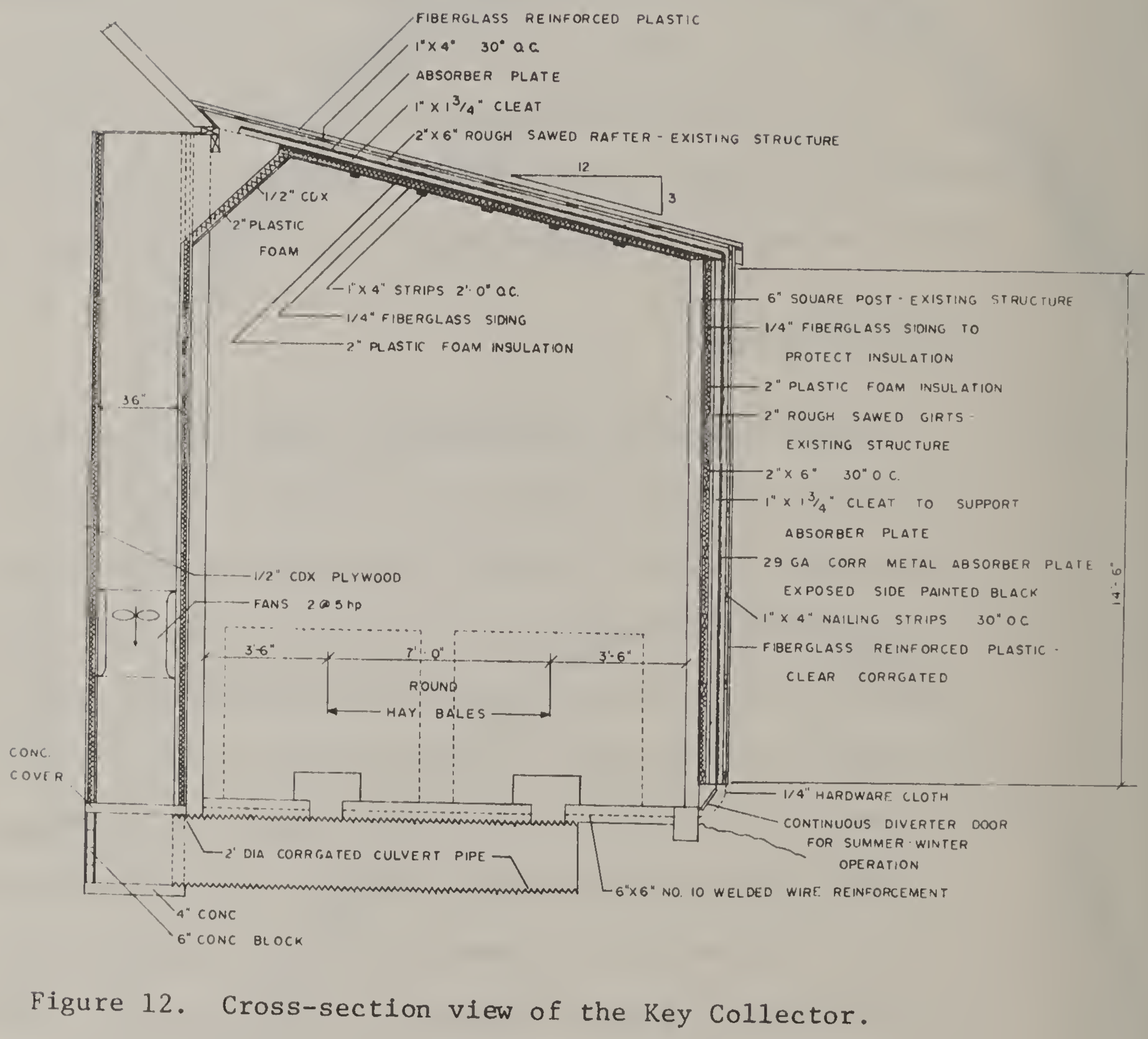

Figure 12. Cross-section view of the Key Collector.

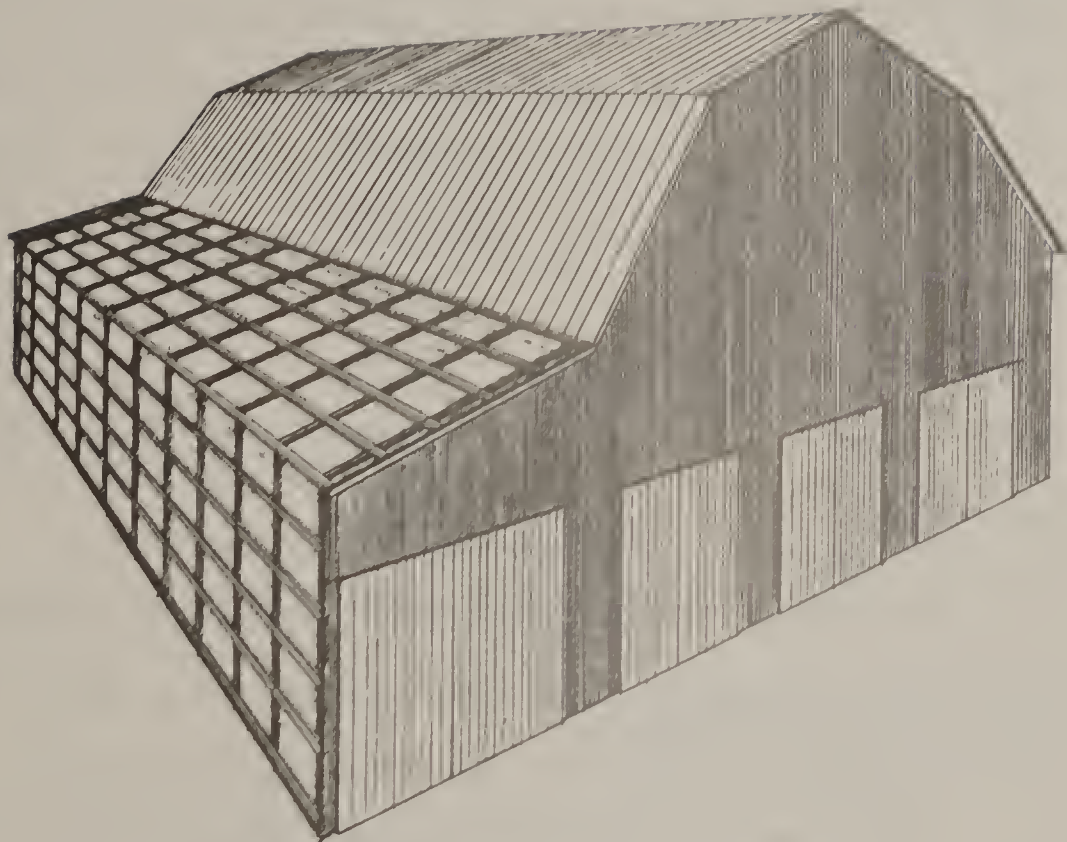

Figure 13. Pictorial view of the multi-purpose collector on the Key Farm.

per square foot for the unit, retro-fitted in an existing shed, was $6.37 per square foot. A cost breakdown for the components is shown in Table VII.

Table VII. Cost Breakdown of the Key Collector

Component	Cost	Component Cost as Percentage of Total Cost
Lumber and supplies	$1,678.00	26.9
Fans	1,335.00	21.4
Concrete and masonry	1,057.00	16.9
Electrical wiring	797.00	12.8
Reinforced fiberglass plastic	772.00	12.4
Culvert pipe	600.00	9.6
Insulation	243.00	

The Operational Procedure

No hay was dried in this unit in 1982. A severe windstorm blew off the roof portion of the facility in late spring and it was not replaced in time for hay drying. All of the hay presently grown by Mr. Key is fescue and fescue/grass misture. It is expected that there will be a shift to alfalfa hay production in the future. The questionable cost-benefit advantage of drying fescue were recognized before initiating this demonstration. Fescue hay does not have leaves that are easily lost. It also dries more quickly than alfalfa hay and its feed value is much less. We do not have data on the economics of solar drying of fescue hay. It is felt that it has a negative benefit. The anticipation that Mr. Key will produce alfalfa hay, utilize the facility for tobacco curing and use it as a tobacco stripping room - utility room are the bases for our expectation of feasibility for this demonstration. Mr. Key used the unit

for supplementary tobacco curing in 1981 and 1982. He reports that he had no "barn scald" or molding either year. Farmers in his locality had widespread damage both years. Mr. Key is the type of individual who will utilize the investment in the facility to fully recover the cost. He has in this solar building a space that is insulated, and has a strong concrete floor. He had no similar space on the farm prior to this addition. Most likely the cost could be justified if it were never used for solar heating.

Performance of the Collector

This collector was not monitored in 1982 and was one that we had expected to evaluate in 1983. This will be done if funds are available. The efficiency of this collector will be similar to the monitored collector at the Manley Farm (see Figures 9 and 10). The roof and wall sections at each location are of identical design. Efficiency of the Manley collector averaged 49%.

DEMONSTRATION 9

The Farm

Billy Spence farms 1,500 acres in Crockett County. He cuts 30 acres of alfalfa hay, and 60 acres of fescue hay. He grows 10,000 bushel of wheat, 15,000 bushel corn and 800 acres of soybeans. He keeps 100 brood cows and finishes 300 - 400 head of hogs each year. He is also in need of a heated shop area. The Tennessee multi-use system is well adapted to the wide diversification of his operation.

The Collector Used

A multi-use dryer (see Figures 9 and 10 on pages 31 and 32) using solar heated air was constructed on this farm. The 28' x 40' (inside dimensions) building accommodates 24 large round hay bales at each loading. Details of the collector are given in the "Multi-Purpose Dryer for Large Hay Bales Using Solar Heater Air" section beginning on page 29 and will not be repeated here.

The structure was located adjacent to a 14,000 bushel grain bin that is used for drying wheat, corn and soybeans. A connecting duct system were installed.

Total cost of the Spence multi-purpose unit was $23,404.00 of which $9,000.00 was paid by this program as a cost-share. The total collector area (walls plus roof) is 1,866 square feet. Cost per square foot of collector was $12.34. Cost per square foot of the building was $19.37. A breakdrown of costs for the components of this demonstration is shown in Table VIII.

Table VIII. Cost Breakdown of the Spence Collector

Component	Cost	Percentage of total materials cost
Lumber and materials	$4,368.00	33.4
Concrete	3,029.00	17.5
Fans	1,995.00	11.5
Site preparation	1,750.00	10.1
Glazing materials	1,194.00	6.9
Insulation	977.00	5.6
Culvert pipe	960.00	5.5
Trusses	895.00	5.2
Electrical materials	742.00	4.3

The Operational Procedure

One hundred fifty large bales of alfalfa hay were dried on the Spence unit in 1982. Mr. Spence did not complete the building as early as desired in the spring of 1982 and the first cutting of alfalfa was delayed. All hay that was cut was successfully dried. Quality of the hay was evaluated as high but no forage analysis tests were conducted this year. This determination will be made in 1983 if funds permit.

Procedure for cutting, baling and drying the alfalfa is explained in the section which details the operation of the Multi-Purpose Dryer For Large Hay Bales beginning on page 29. Mr. Spence used the same methods, in general, as the other operators of these dryers.

Twelve thousand bushels of wheat were dried in 1982 in the 14,000 bushel bin that is connected to this collector. The bin used 294 gallons

of propane gas in addition to the solar energy utilized. Value of the energy saved by the collector in equivalent propane gas was $345.00.

Performance of the Collector

This demonstration was not monitored in 1982 and was one that was expected to be evaluated in 1983. The efficiency of this collector will be similar to the monitored collector at the Kenneth Manley farm (see page 43).

DEMONSTRATION 10

The Farm

The Kenneth Manley's farm about 800 acres of land in Jerrerson County near New Market. They have a milking herd of approximately 180 cows, grow 12 acres of burley tobacco and grow 20,000 bushels of corn for grain. This outstanding farmer grows 90 acres of alfalfa hay which is fed to the dairy cows. He also grows approximately 70 acres of soybeans and wheat in a double cropping system.

The Collector Used

A Multi-purpose dryer using solar heated air was constructed on the farm. The 28' x 40' (inside dimensions) building accommodates 24 large round bales at each loading. Details of the collector are given in the "Multi-Purpose Dryer for Large Hay Bales Using Solar Heated Air section beginning on page 29 and will not be repeated here.

The structure was located adjacent to two 5,000 bushel grain bins that are used to dry corn and wheat. A duct system from the collector building to the bins allows air to be diverted for drying at either the bins or the hay drying building.

Cost of the Manley Multi-Purpose unit was $17,737.00, of which 50% or $8,868.00 was paid by this program as a cost-share. The total collector area (walls plus roof) is 1,896 square feet. Cost per square foot of collector was $9.88. Cost per square foot of the building was $14.68. A breakdown of costs for the components for this demonstration is shown in Table IX.

Table IX. Cost Breakdown of the Manley Collector

Component	Cost	Percentage of total materials cost
Lumber and Materials	$5,614.00	38.3
Fans	1,995.00	13.6
Glazing materials	1,501.00	10.3
Concrete and masonry	1,448.00	9.9
Insulation	977.00	6.6
Culvert pipe	960.00	6.5
Excavating	769.00	5.3
Trusses	755.00	5.2
Electrical materials	685.00	4.7

The Operational Procedure

Approximately 400 large round bales of alfalfa hay were dried on the Manley unit in 1982. This represented six cuttings on 90 acres. Quality of the hay dried was of above average quality. No forage analysis tests were made in 1982, but this evaluation will be made in 1983 if funds are available.

The procedure for cutting, baling and drying the alfalfa hay was developed on Mr. Manley's farm. This schedule is outlined in the Operational Procedure Section beginning on page 43.

Two thousand-fifty bushels of wheat was dried from 19% moisture to 13% moisture in June 1982. All of the heat for drying was furnished by solar energy.

Ten thousand bushels of corn were dried from 21% to 14% moisture in the fall of 1982 with the use of solar heat only.

Performance of the Collector

The multi-purpose collector unit on the Manley farm was monitored and the efficiency was calculated. Average daytime efficiency was determined to be 49%. Peak efficiency was 53%.

Table X. Summary-Type of Farm Collectors

	Farm			Collector
	Type	Size	Crops	Shop	Type
1	G L	450	C S W	X	P
2	D G	800	C W	X	P
3	G L	500	C S W	X	P
4	G L	400	C S W	X	P
5	G	2,000	C S W	X	P
6	G	950(A)	C S	X	P W
7	G L	1,300	C S W		W
8	L T	217	H T	X	M
9	G L	1,500	C H S W	X	M
10	D G	800	C H S W	X	M

D = Dairy
G = Grain
L = Livestock
T = Tobacco

C = Corn
H = Hay
S = Soybeans
W = Wheat
T = Tobacco

M = Multi-Purpose Barn
P = Portable
W = Wrap-Around

Table XI. Summary of All Collector-Costs and Areas

Farm no.	Collector size ft^2	Total collector cost (materials & labor)	Total cost per sq ft
1.	288	$ 900.00	$ 3.13
2.	576	1,800.00	3.13
3.	576	1,800.00	3.13
4.	288	900.00	3.13
5.	864	2,700.00	3.13
6.	1,365	900.00/1,673.00	3.13/1.23
7.	1,149	2,561.00	2.23
8.	1,120	7,143.00	6.38
9.	1,866	23,404.00	12.54
10.	1,866	17,737	9.50

Table XII. Summary of all Collectors - Payoff for the 10 Demonstrations

Demonstration no.	Value of solar energy utilized 1981	Value of solar energy utilized 1982	Collector cost	Simple[1] payback period years
1.	---	$ 191.00	$ 900.00	4.7
2.	---	565.00	1,800.00	3.2
3.	$ 40.00	49.00	1,800.00	36.7
4.	---	210.00	900.00	4.2
5.	---	1,474.00	2,700.00	1.8
6.	---	97.00	1,673.00[2]	17.3
7.	230.00	509.00	2,561.00	5.0
8.	---	[3]	7,143.00	---
9.	---	1,415.00[4]	23,404.00	16.5
10.	---	3,680.00[5]	17,737.00	4.8

[1] The simple payback period is based on the actual benefit received in 1982. Benefits greater than those reported in 1982 are expected in future years for some collectors.

[2] Only the Wrap-around collector has been used on this farm to date of this report.

[3] No alfalfa was grown and no hay was dried on this collector in 1982.

[4] Based on estimated saving of alfalfa leaves, $1070.00, and drying of 12,000 bushel of wheat. No value was assigned for reduced weather loss, reduced labor, or other advantages brought about.

[5] Based on estimated saving of alfalfa leaves, $2,852.00, and drying of 12,050 bushels of wheat and corn, $828.00.

EDUCATIONAL ACTIVITIES AND PUBLICATIONS

Group Visits and Tours

A list of touring groups is given:

1. A farm-city week group of 45 visited Demonstration 1, the Keller farm, in September 1982.
2. A Soil Conservation District group of 32 from South Carolina toured Demonstration 10, the Manley farm in August 1982.
3. The Jefferson County Annual Farm Field Day was held at the Manley farm in August 1982.
4. A visiting group of 5 electric company executives from Brazil was taken to the Manley farm in December 1982.
5. A field day for West Tennessee farmers and county extension leaders was held at Demonstration 9, the Spence farm August 25, 1982, 35 attended.
6. A livestock and solar field day was held at Demonstration 8, the Key farm in August 1981 with 45 in attendance.

Visits by Individuals

An accurate count of the visits of individuals to each farm is not available. It is estimated that an average of at least 25 persons have singly been on the site of each demonstration to seek information on the systems in use.

Newspaper Articles on the Demonstrations

1. Greeneville Sun, Aug. 16, 1982. "Using Solar Heater to Dry Hay."

2. Cookeville Herald, August 17, 1982. "Solar Heater Dries Hay."
3. Lebanon Democrat, August 16, 1982. "Solar Hay Dryer Increases Quality."
4. Clarksville Leaf Chronicle, August 16, 1982. "Farmer Using Solar Heater to Dry Hay."
5. Murfreesboro Journal, August 17, 1982. "Farms Go Solar Too."
6. Athens Post Athenian, August 13, 1982. "Farmer in New Type of Project Storing Sunshine."
7. Brownsville States Graphic, August 13, 1982. "Solar Heated Barn Improves Hay Quality."
8. Jackson Sun, August 9, 1982. "Storing Sunshine." A full page article with pictures was published.
9. The (Memphis) Commercial Appeal, August 26, 1982. "Farmers See Barn Using Solar Heat." Feature article with pictures.

Magazine Articles Concerning the Demonstrations

A feature 2 page article, "Demonstrating Solar Energy in Tennessee" was published by the Tennessee Farmer Magazine. This is Tennessee's largest farm magazine.

Talks Presented by University of Tennessee Personnel

1. Kenneth E. DeBusk presented a 30 minute talk on the "Tennessee On-Farm Solar Drying of Crops and Grains," project to the annual meeting of the Tennessee Section American Society of Agricultural Engineers in October, 1982.
2. Kenneth E. DeBusk will present a paper at the Southern Association of Agricultural Scientists Annual Meeting in Orlando, Florida February 7, 1983 on the demonstration project.

Future Publications

Fact sheets will be prepared as follows:

1. The Portable Solar Collector as a Multi-Purpose Heat Supplier
2. Drying Grain With Solar Energy - Experiences in the On-Farm Demonstration Project for Drying Crops and Grains
3. Field Testing of the Tennessee Multi-Purpose Collector for Drying Large Hay Bales and Grain
4. The Wrap-Around Bin Collector for Drying Grain
5. Is Solar Energy for Grain Drying Feasible?

Future Activities Concerning the Tennessee On-Farm Solar Drying of Crops and Grains Project

1. We expect to continue monitoring some of the installations in 1983.
2. We will work with farmers to more efficiently utilize the existing collector units.
3. We will enlist local newspapers to print articles on more of the demonstrations in 1983.
4. We will encourage more tours and field days including the demonstrations.
5. We will prepare publications using topics listed in the "Future Publications" sections of this report.

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Final Report

Extension Demonstration

for

On-Farm Solar Drying of Crops and Grains in Virginia

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Sponsor

USDA/DOE
Cooperative Agreement No. 12-05-300-514
VPI & SU Project No. 231-11-110A-002-3337191

Duration

November 30, 1980 to April 30, 1983

December 13, 1982

Extension Demonstration
for
On-Farm Solar Drying of Crops and Grains in Virginia

Contents

I. Introduction

To insure continuing interest in solar substitution for fossil fuel use, ten cost sharing on-farm solar assisted crop drying or curing demonstrations have been established in Virginia in the last two years. The Extension activity has involved (1) the selection of farm cooperators, (2) system designs, (3) supervision of on-farm construction or fabrication, (4) obtaining cooperator agreements and subsidization of construction costs, (5) testing and monitoring of systems operations, (6) evaluation of reliability, effectiveness, and economics of systems, and (7) dissemination of information on farmer use of solar systems to aid with crop drying.

The project was funded by a grant from USDA/DOE in the amount of $101,840 of which $23,575.73 was paid or provided in materials and services to ten farmers for approximately 1/2 the cost of construction of the on-farm facilities. Demonstration reports (attached) give the total cost of each constructed facility including the farm cooperators share. Additionally, the faculty and staff at Virginia Polytechnic Institute and State University made considerable contribution, part of which was covered by the grant. A $9,680 share of the grant was provided to the Agricultural Economics Department for an economic evaluation of the demonstration units.

This report discusses the overall project including its status, educational activities, and plans for future effort. A report on the demonstration by each farm cooperator gives details of design and operation, and economic evaluations.

II. Objectives

The goal of the activity was to increase the quantity and quality of available information on the use of solar assist systems for crop drying or curing by developing on-farm demonstrations. Objectives which were thought to be obtainable in the original time frame of three years are as follows:

1. To establish 10 additional on-farm demonstrations making use of solar assist systems which are technically and economically feasible to aid in the drying or curing of crops.

2. To increase the capability of extension agents to provide information and technical assistance to crop producers on the use of solar as a substitute energy source.

3. To make specific applications of solar technology where appropriate and feasible as developed by DOE/USDA-SEA research programs and involve SEA agricultural engineers at Suffolk, Virginia in an advisory role.

4. To monitor the solar demonstration units to determine the investment cost, operating costs, non-renewable energy saved, and other economic feasibility criteria for cost effectiveness and evaluation.

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5. To incorporate and test environmental controls and related technology which is aimed at improving the efficiency of drying or curing while maintaining product quality.

6. To use information dissemination methods in cooperation with local Extension Agents to inform potential solar users of construction methods, materials, application, operation, and potential benefits.

7. To identify additional opportunities and incentives for applications and adoption of solar energy in crop drying or curing.

Attainment of the above objectives required the selection of farm participants and drying applications, preparation of design reports for the application of solar technology to crop drying, construction of facilities, monitoring the operation of each demonstration system, monitoring the initial and operating costs, training of Extension Agents, developing plans for information dissemination, and identification of additional opportunities and incentives for solar energy use.

III. Demonstration Selection

Extension Agents were advised of plans to establish solar crop drying demonstrations and criteria for selection of cooperators. Their response resulted in 27 farm visits to evaluate the potential for a demonstration. Project personnel met and tentatively selected ten cooperators based on farmer interviews, location, diversity of usage, potential for cost effectiveness, and photographs of existing facilities. Contracts were prepared and either mailed or taken to the prospective cooperators for their signatures. Thirteen design reports were prepared for potential demonstrations before ten signed commitments were made. A sample of the contract between the cooperator and Virginia Polytechnic Institute and State University is attached. Three potential cooperators for whom designs were prepared declined to participate for one or more of the following reasons: (1) status of estate unclear due to death in family, (2) financial stress, and (3) unattractive potential payback.

The cooperators, who entered into agreements to participate in the demonstrations, may be generally classified as progressive farmers who are innovators or early adopters. As the individual reports will show, the range in farm size was from small to very large. Eight of the ten demonstrations involve peanut drying in southeast Virginia since this appeared to be one of the better applications of solar energy. A grain drying and shop heating demonstration was located in northern Virginia and a tobacco curing and grain drying demonstration was located in southern piedmont. Swine house heating was associated with one demonstration unit. The objective of establishing ten on-farm demonstrations was met. More diversification in solar crop drying usage and statewide coverage was desired than obtained. Figure 1 shows the location of both funded and other solar crop drying systems in Virginia.

Figure 1. Location of Solar Crop Dryers in Virginia.

IV. System Designs

Thirteen solar crop drying system designs were prepared and approval for construction and cost-shareing was received for twelve from the Solar Crop and Grain Drying Advisory Committee. Only ten designs were actually constructed and cost-shared. Seven of the designs were associated with trailer crop drying systems in the major grain and peanut producing area of Virginia. Four of the trailer systems (3-6 trailer and 1-8 trailer) were of new construction based on designs developed by the project manager. Three additional eight trailer units have since been constructed which were not cost-shared. Three of the trailer systems were retrofitted with solar collectors on existing structures in use 15 or more years. One design, employing a portable collector to aid with grain and peanut drying and including a heat storage for swine house heating, can be attached to a trailer drying system without being an integrated part of it.

One design is used in the northern part of the state for grain drying and shop heating as a part of an existing structure. The most costly design was prepared for a tobacco and grain farmer in southside Virginia. It involved integrated collectors in a shop attic and over a heated water storage arrangement. The two designs which were approved but not constructed included a baled hay and grain dryer and a grain dryer and shop heater.

All designs employ custom type farm constructed collectors. In every case an attempt was made to design the solar assist crop drying system to be the least costly to construct, to require little or no management to operate, and to last a minimum of 15 years. All plans were drawn to facilitate construction by the farm cooperator or his workers. In a few cases, local building contractors constructed the facility. A bill of materials and an estimated cost of construction accompanied each design. The attached fact sheets include a floor plan and section for each facility. Complete plans are available from the project manager.

The objective related to technical and economic feasibility was largely met; however, there are limitations in both areas which will be discussed near the end of this report.

V. Extension-Cooperator Relationship

The second contact with the prospective cooperator usually involved the presentation of a preliminary design and a sub-contract outlining the agreement between him and VPI & SU under cooperative agreement no. 12-05-300-514. The sub-contract especially for cooperators in the project entitled "Demonstrating Solar Drying of Crops and Grains in Virginia" was prepared and approved by legal counsel for the University. The cooperator was encouraged to review the contract with his personal attorney before signing. A sample contract is attached (Appendix A).

Under terms of the contract, the cooperator was responsible for construction and operation of the solar crop drying system. At two locations considerable University assistance and supervision on construction was necessary especially as related to heat storage systems.

The cooperators were permitted to submit statements of construction costs in two segments and were reimbursed for the University share accordingly. After the system was completed, and total bills submitted, the University reimbursed the cooperator for the share of construction costs up to 50% of the total cost or the maximum amount shown on the contract. An example of billing statements is attached (Appendix C).

Cooperators were instructed to operate their facilities in a way mutually satisfactory to them and the project manager. The cooperators were supplied with log sheets to be completed with information not readily obtained by other data logging equipment or instrumentation. This was the least satisfactory part of the association. All ten solar demonstration units were constructed and operated with varying degrees of success and a high degree of cooperator satisfaction.

VI. Monitoring Procedure

A difficult data acquisition problem was posed by the need to collect data at ten different farmsites where most of the crop dryers were operating at the same time. It was proposed that sufficient data be collected over a three year period to obtain the energy gain of each system, the efficiency of each total system, the fuel savings, and the cost accounting for each system. A need existed for several reliable acquisition systems to be left at the demonstration sites unattended for two or more weeks.

A decision was made to purchase three data acquisition systems to monitor three sites at a time. Hence, no data is available for a total harvesting season at any one site other than information supplied by the cooperator.

The data logger selected for automatic data collection was an A. D. Data Systems ML-20A data logger developed by Techtran*. This minilogger is capable of recording from 2 to 20 channels (sensors) of data. Real time is recorded for every scan interval and includes day, hour, and minutes. Also, eight characters are available for digital input ports and are used to store on-site or other digital information. The data is stored on a magnetic tape cassette with 100k of character storage; however, no paper print-out is available for back-up in chase of loss of system memory or magnetic tape cassette failure. A cassette will last 20 days for a scan interval of 1 hour and 20 channels of recorded data. Scanning rates range from 15

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* The use of trade names in this report does not imply endorsement of the product nor criticism of other products not mentioned.

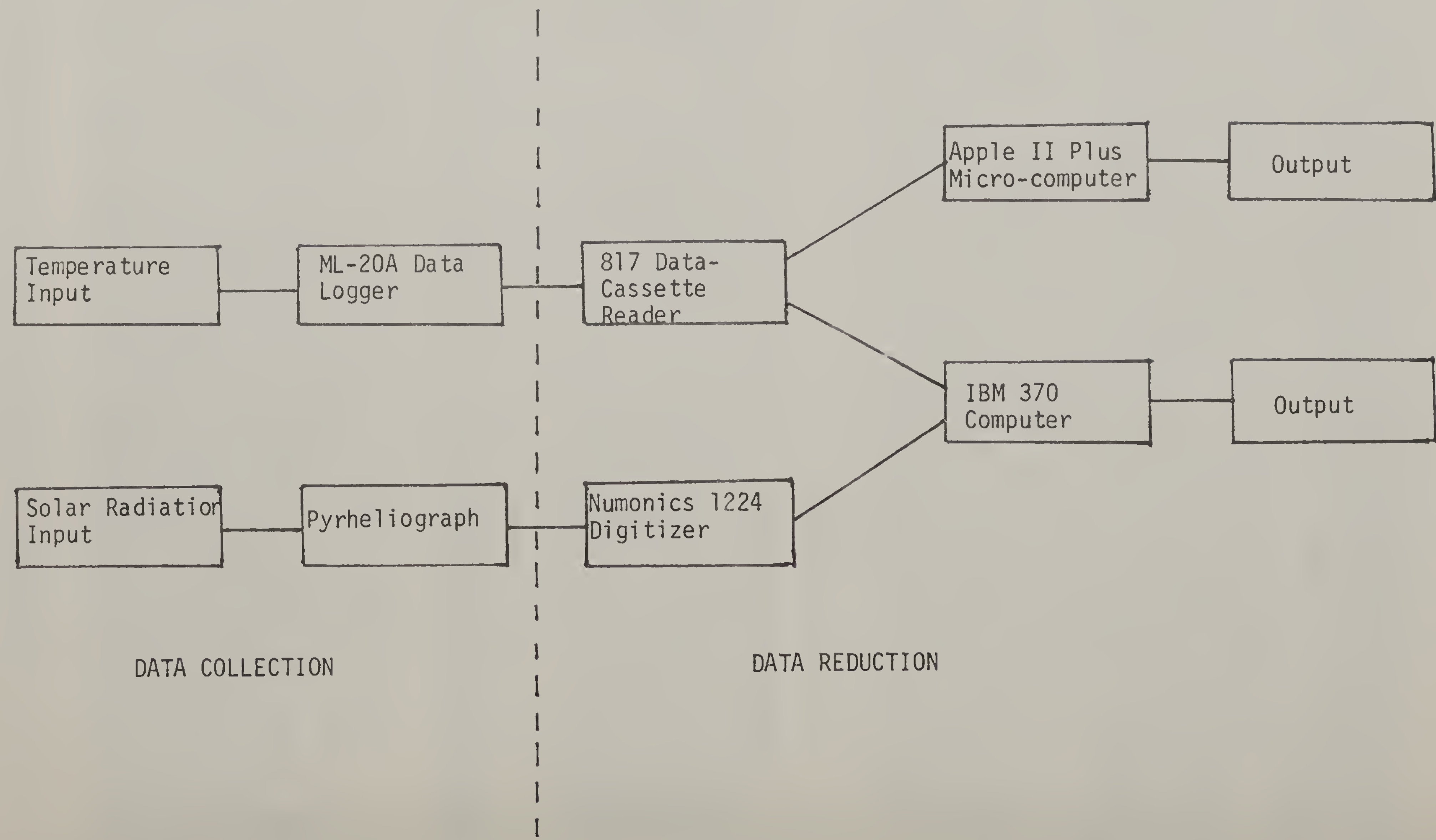

Figure 2. Data Collection Procedures.

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seconds to 1 hour with 7 possible intervals for selection. The data logger may be controlled by manual, internal, or external modes. The manual mode permits a data scan without interrupting the data collection process. External mode permits the data logger to be controlled by another microprocessor. With internal mode, the data logger controls the scanning of sensors and records the time and input data. After the thermocouples are connected to the ML-20A, the data logger may be put into the internal record mode in less than 5 minutes.

The advantage of the ML-20A data logger is that it operates on a battery power supply which can be charged with an AC supply and will operate for 20 days with 16 hours of charging. This enables the logger to continue operating during power outages or where electric power may not be readily available. Although an independent power source was viewed to satisfy the needs at demonstration sites, two important sets of data were lost at one site due to malfunction of the logger in response to electric power surges caused by lightning or other sources. In each case, the program on the main processing board was destroyed. The manufacturer has solved the problem by redesigning the processing board. This included the installation of CPU boards to increase battery life, new software to enhance operation, and high voltage reeds for operation in harsh environments.

A disadvantage of the ML-20A was the connection of thermocouples to the data logger. Each thermocouple required a pin to be soldered to the copper and constantan wires for connection to the data logger. This was very time consuming and limited the flexibility of the system for use from one site to another. The problem was overcome by developing a junction box with terminal bars for each data logger. The junction boxes were calibrated based on a reference temperature of 0°C and it was found that each thermocouple measured within $\pm$ 0.5°C.

Another parameter needed to complete the temperature data base was wet bulb temperature for obtaining relative humidity. Six wet bulb temperature sensing units were constructed by using a small shaded pole blower to pull air through a tube and across two thermocouples. One thermocouple sensed dry bulb air temperature. A bottle with a wick in the cap was mounted near the center of the tube enabling one thermcouple to be positioned in a saturated wick. One unit was calibrated in a laboratory experiment where wet and dry bulb measurements were taken five times daily for two weeks. The wet bulb unit was within $\pm$ 0.5°C for dry bulb measurements and $\pm$ 1.0°C for wet bulb measurements. A hygrothermograph was placed at each site as a backup unit for measurement of ambient air conditions.

Solar radiation was measured using a Belfort strip chart pyrheliograph chosen because of cost and ease of use. The pyrheliograph is capable of recording daily incoming solar radiation for 7 or 30 day periods. The charts were digitized using a Numonics 1224 digitizer available within the Agricultural Engineering Department.

To properly analyze a solar crop drying system, information on static pressures, voltage, amperage, and air velocity is needed. Also, it is helpful to know when an event occurs such as length of time a fan or burner operates.

Three event recorders (292-4 by Gulton Industries) were purchased and used to monitor fan and burner operation. The recorders are capable of measuring 4 events simultaneously over a 30 day recording period. Other data normally collected with the aid of instruments when on-site included static pressure, voltage, amperage, airflow and moisture contents. A Dwyer model 400 manometer was used to measure static pressure under varying operating conditions. Voltage and amperage were measured using a multivolt clamp-on meter and crop moisture content was determined by a Dickey-John moisture meter. Air velocity was measured using a velometer and hot wire anemometer. The farm cooperators were asked to record the dial reading of electric meters and fuel tanks daily, record initial and final moisture contents of entering and exiting crops, and log general operating procedures.

VII. Data Analysis

Two modes of data analysis were considered which included the on-campus mainframe computer and a portable mini-computer. Both options were employed.

The first option involved the use of an on-campus IBM 370 computer. A 817 Datacassette developed by Techtran was interfaced with the IBM 370 computer to transfer data from the magnetic tape cassette into the storage of the computer. It provided the necessary software for direct transfer of data, thus eliminating any special requirements for developing software or hardware for interfacing the two components.

Data reduction from strip charts involves the use of a Numonics 1224 Digitizer available within the Agricultural Engineering Department. The digitized data is transmitted to a TI 7330 terminal where it is placed on a cassette and immediately transferred online to the IBM 370 computer.

The second option developed for analyzing collected data involves the use of a portable Apple II Plus minicomputer. The system is equipped with a screen monitor, two disk drives, and a NEC PC-8023A-C 80 character printer. A Grappler interface board is used to interface the NEC printer to the Apple II. An interface board, model 7710A developed by California Computer Systems, is used to interface the 817 Datacassette with the Apple II. This permits the Datacassette to be used both with the Apple II and the IBM 370 computer by changing the duel inline plug dip switches. The data can be transferred from the cassette to the screen or placed in memory. Project personnel developed the software for transferring data from the memory of the Apple II onto a floppy disk and for formatting output and plotting graphs using any two data points in a data file generated by the ML-20A data loggers.

Field analysis requires transferring the data from the cassette onto a floppy disk. Programs are written in basic language for analyzing the sensible heat grains of the solar collector and developed to run interactively. Input information requires location of ambient, fan inlet, fan outlet, collector inlet, and collector outlet thermocouples,

volume of airflow, and specific volume. This permitted a common program to be used for analyzing any one of the solar projects. The program also permits special sections to be analyzed if more than one component supplies heat. Other features of the program include printer output of sensible heat gains in gallons per hour, BTU per hour, or both, graphical display of two sets of data on the same plot on the screen, graphical output on the printer, and options to display and print more than one graph on the screen or printer. Field analysis of the data gives immediate information on the performance of the solar drying system. A more comprehensive analysis of the data can be obtained using a mainframe computer; however, the mini-computer gives a quick and less expensive analysis where a relatively small number of parameters are involved. The data collection system has been very satisfactory except for the field problem with the data loggers and manual recording of data.

VIII. Reliability, Effectiveness, and Economics of System

Any evaluation of on-farm demonstration units needs to take into consideration several factors affecting their construction and use. Seven of the units have been used or partly used for two crop drying seasons. Of these, five were completed and used for two seasons; one of a two unit system (J. Butler) was completed and used two seasons; one unit (Edwards) was used for crop drying for two seasons but is just being readied for swine house heating during late fall, 1982. Two of the units (C. Butler and Hottel) were used during one drying season. Use of one of these was delayed due to a loss in shipment of fiberglass panel. One of the units (Winn) was used only during a part of one season because of leaks in the plumbing and other problems discussed in the individual report.

Another factor affecting evaluation was the difficulty of monitoring ten units at the same time. Consequently, very good information has been gathered on some operations and only limited amounts obtained from others. Two of the data loggers malfunctioned due to voltage surge at one location and all three had to be returned to the factory for repairs which limited their availability for use.

Other factors which influence evaluation are the different modes of operation used by farmers and effects of weather conditions on operation. Generally, when a farmer is harvesting crops he feels he has to spend full time on saving the crop and little time recording data. To him, extra work such as weighing the crop, taking moisture samples, and reading meters may be critical in an already labor short time period. It is important that a solar crop dryer operate without attention by the farmer. Weather conditions during harvesting affects the rate at which the crop is harvested, but also affects the efficiency of the solar system. Solar crop dryers were less efficient as demonstrated in the latter part of the 1982 fall harvesting season when field drying was exceptionally fast.

Table 1 shows the location, use, and other characteristics of the solar crop drying units. The units which cost the most to construct are those that include some type of heat storage. They are also the ones that are the most difficult to construct, operate, and on which to receive a return of investment. Table 2 gives the results of use of the solar crop drying units where an effective evaluation can be made. The demonstration units should not be compared since many variables may be reflected in the results. In some cases, two years of data give different results than when using only one year. For instance, solar dryers, when used only for peanuts, showed around 30% savings in 1981 but somewhat less in 1982. Field drying conditions were more favorable in 1982 than in 1981. In some cases, the results in the table are associated with the drying of only one crop when multi-use of collector was projected in the design.

Several observations may be based on the information shown in Tables 1 and 2. More specific information on the operation of these demonstration units may be obtained from the attached fact sheets (Appendix B).

1. Solar collectors for crop drying can be constructed for less than $2.00 per sq. ft. when heat storage is not included.

2. Heat storage for crop drying is not practical or cost effective except possibly for tobacco curing in selected situations.

3. Solar collectors as a part of existing buildings cost as much to construct as integrated collectors in new structures except those existing structures with large surfaces using a bare plate (Hottel).

4. Because of investment required for heat storage (Edwards), a solar collector without storage is more cost effective for crop drying than is a solar collector with storage for crop drying and swine house heating.

5. The payback period for solar crop drying systems is mainly related to original investment and use. High investment or low use results in long payback periods.

IX. Educational Activities

An effort has been made to publicize the solar crop drying demonstration projects to both farmer and Extension Agent audiences. One to two years of results from farm operations will provide additional opportunities for educational activities. Copies of some of the media articles and other information are attached (Appendix D). The following is a listing of educational activities undertaken:

1. A solar crop drying fact sheet series was prepared for distribution to producers and agents (Appendix B).

Table 1. Characteristics and Costs of Solar Crop Drying Units.

Cooperator	Location (County)	Use	Collector Area (Sq. Ft.)	Storage	System Cost ($)	Unit Cost ($/sq. ft. of collector)
Drewry	Sussex	grain, peanuts	1,940		2,927.04	1.51
Pulley	Southampton	grain, peanuts	1,933		2,714.26	1.41
Veliky	Greensville	grain, peanuts	1,827		3,309.20	1.81
Francis	Southampton	grain, peanuts	2,418		3,436.01	1.42
Copeland	Isle of Wight	grain, peanuts, greenhouse	3,160*		3,830.41	1.22
C. Butler	Isle of Wight	grain, peanuts	2,625*		4,714.50	1.80
J. Butler	Isle of Wight	grain, peanuts	3,204*		4,599.19	1.44
Hottel	Loudoun	grain, shop	7,926*		2,615.90	.33
Edwards	Isle of Wight	grain, peanuts, swine	576	30 tons rock	5,983.39	10.39
Winn	Pittsylvania	grain, tobacco, shop	1,272	10,000 gal. water	13,021.57	10.23

* Existing structure retrofitted.

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Table 2. Energy Use and Economics of Solar Crop Drying Demonstrations

Cooperator	Total Fuel Energy (gal. LPG)	Energy Saved by Solar (gal. LPG)	% Savings	Present Value($) 15 yr. investment	Payback Period (years)	
					w/Tax Credits	w/o Tax Credits
Drewry	1,783	764	30	6,695.81	4.0	5.3
Pulley	1,112	476	30	4,343.94	6.5	8.7
Veliky	1,017	490	32.5	4,642.03	7.6	10.2
Francis	6,478	1,898	29	17,306.46	1.8	2.4
Copeland	1,267	800	38.7	7,010.40	5.1	6.8
C. Butler	4,000	1,094	21.5	8,679.88	4.5	6.1
J. Butler	1,643	800	32.7	7,578.03	6.3	8.4
Hottel	1,140	760	66.6	6,029.89	4.3	5.7
Edwards	8,191	959	10.5	8,403.72*	6.9	9.2
Winn**	8,960	936	10.4			

* Includes projected savings for swine house heating.

** Insufficient information - probably not economically feasible as constructed.

2. Complete plans and bill of materials for each project were prepared and made available to Extension Agents for distribution upon request. The 6 trailer and 8 trailer solar crop dryer systems are now standard plans available through the building plan service.

3. A flyer on the proposed development of each solar crop dryer was prepared for handout at meetings and on tours.

4. The overall project and local demonstrations have been reported in news articles, magazine articles, and radio and TV programs and releases. Local news articles and programs were generally prepared by Extension Agents.

5. Slides were prepared and made available to agents for local use.

6. Solar crop drying demonstrations have been a stop on county farm tours.

7. Agent training has been provided during normally scheduled in-service training programs.

8. Information on solar crop drying has been presented at county and area production meetings for farmers.

9. An exhibit prepared by the Extension Division has featured information on solar crop drying in presentations within the state.

Generally, the objectives of the project relative to educational information and dissemination have been obtained. It might have been difficult to release much additional information without experience with systems construction and operation.

X. Summary

The solar crop drying demonstration project has been successful from the standpoint of accomplishment, experience with operations, information dissemination, development of a data collection system, and potential for future application. Nine of the ten demonstrations are immediately justifiable economically. One system needs further testing and greater application. Some systems can and should be used for more crops and longer periods of time to improve economic return.

It was not possible to achieve some of the objectives related to differences between types of collectors, arrangement of various components, use of various absorbers, and airflow effects on efficiency. The difference in external factors from one farm to the next is so great and uncontrollable that any attempt at comparison is meaningless. To determine minute differences will require highly instrumented research beyond the scope of this project.

Appendix A

Sample Sub-Contract

Subcontract

between

and

Virginia Polytechnic Institute and State University

Purpose of Agreement

Virginia Polytechnic Institute and State University (Virginia Tech) is the recipient of Cooperative Agreement Number 12-05-300-514 from the Science and Education Administration - Extension, U. S. Department of Agriculture, for a project entitled, "Demonstrating Solar Drying of Crops and Grains in Virginia".

A major feature of this project is that Virginia Tech will work with certain farmowners to demonstrate the technical feasibility of using solar energy for drying of crops and grains. This will involve cooperating with the farmowners in developing a solar heating system appropriate to his needs, reimbursing the farmowner for certain costs, and evaluating the performance of the system for a certain period after its installation.

This Reimbursement Agreement defines the conditions under which Virginia Tech will cooperate with ______________________________ (the farmowner), and the terms of Virginia Tech's reimbursement to the farmer, to develop, install, operate, and evaluate a solar drying system for crops and grains on the farmowner's property.

Period of Agreement

This agreement will become effective on the date of the last signature. It will remain in effect through ____________________. Virginia Tech's Cooperative Agreement with USDA terminates annually on _____________, but may be renewed annually by USDA. Therefore, Virginia Tech reserves the right unilatterally to extend this agreement annually to the following ______________ for a period of three years, unless the parties have exercised their rights to terminate this agreement.

Virginia Tech Agrees:

1) To assist the farmer in designing, selecting, and/or planning a solar drying system for ____

2) To reimburse the farmer ________% of the costs of such equipment, not to exceed $______________. (If these figures are not known at the time this agreement is signed, insert "unknown". A memorandum signed for

Virginia Tech and for the farmowner shall be appended to the agreement and become a part of it to define these figures). Title to this equipment will vest in the farmowner upon acquisition. (Required B.S. if over $10,000)

3) To provide personnel, equipment or instrumentation and services necessary to evaluate the performance of the solar drying system. None of the equipment used for this purpose shall become the property of the farmowner.

4) To make an economic evaluation of the solar drying installation.

<u>The Farmowner Agrees</u>:

1) To install and operate for a period of 3 years, a solar drying system for

____

____

____

2) To submit to Virginia Tech a plan for assembly or construction and budget for the solar drying installation. These must be approved by Virginia Tech prior to procurement of the equipment and materials in order that the farmowner may be reimbursed part of the cost. Any change in the approved design or budget must be mutually agreed to and signed by both parties' representatives. Virginia Tech shall be the sole judge of the allowability of reimbursement either in excess of the budgeted amount or for material and equipment not previously approved.

3) To retain for 3 years and make available to Virginia Tech upon request invoices and other records to substantiate the procurement cost of the solar drying system.

4) To allow Virginia Tech access to the property, location and solar drying system, and to maintain this area and system in a manner to prevent safety hazards to Virginia Tech personnel or other persons.

5) To provide Virginia Tech information, such as prior expenses and system performance, which will assist in economic evaluation.

6) To allow, at reasonable times and with prior notice from Virginia Tech, groups of visitors access to the property, location and solar drying system for demonstrations, tours and workshops.

7) To allow Virginia Tech and U.S. Government unlimited rights to publish information about the installation, including data which may be provided by the farmowner.

8) To comply with the provisions of Executive Order No. 11246, dated September 24, 1965, Section 202, Para. (1) through (7), and such rules for implementation as shall be made by appropriate Federal authority. It is noted that the principle effect of Executive Order 11246 is that contractors and subcontractors of the Federal Government "will not discriminate against any employee or applicant for employment because of race, color, religion, sex or national origin [and] will take affirmative action to ensure [such non-discrimination]". It is further noted that Revised Order No. 4 (41 CFR 60-2)

applies the requirements to have a written affirmative action compliance program to any "subcontractor with 50 or more employees and a contract of $50,000".

Virginia Tech and the Farmowner Mutually Agree:

1) That Virginia Tech's representative to the farmowner shall be ______________ and that the farmowner's representative to Virginia Tech shall be ______________

2) That payment to the farmowner shall be made by Commonwealth of Virginia check on the following schedule, and on presentation of a claim for this payment supported by appropriate documentation of the farmowner's expenses.

____

____

____

(Enter mutually agreed schedule. If not known at the time this agreement is signed, insert "unknown". A memorandum signed for Virginia Tech and for the farmowner shall be appended to the agreement and become a part of it to define these figures.)

3) That Virginia Tech will use its best professional efforts in any design assistance it gives, but that it offers no guarantee regarding the performance of any solar drying system and will accept no liability in regard to such system, its effects, or its technical and/or economic feasibility.

4) That it is the intent of both parties that the solar drying system shall be in operation for a period of Three years
Should the farmowner exercise his right to terminate the agreement, Virginia Tech accepts no responsibility or liability for removing the solar drying system or any part thereof, or for restoring any of the farmowner's property to is former condition.

5) That Virginia Tech shall be solely responsible where found liable, to the extent covered by insurance, for the payment of any and all claims for loss, personal injury, death, property damage, or otherwise, arising out of any act or omission of its employees or agents in connection with this subcontract, except in the matters listed above wherein Virginia Tech specifically rejects assumption of any liability.

6) That this agreement may be terminated at any time by either party upon delivery to the other party of written notice 30 days in advance of the intended date of termination.

7) That no member of or delegate to Congress shall be admitted to any share or part of this agreement, or to any benefit that may arise therefrom; but this provision shall not be construed to extend to this agreement if made with a corporation for its general benefit.

8) That this agreement constitutes the entire agreement between the parties, and that it shall be modified only in writing, executed for both parties.

Signed for Virginia Tech

____

Name

Date__________________________

Signed for Farmowner

____

Name

Date__________________________

Appendix B

Crop Drying Series
Fact Sheets

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SOLAR CROP DRYING SERIES

Agricultural Engineering

Solar Crop Drying in Retrofitted Fourteen Trailer Shed

A. J. Lambert and J. P. Harner, III

A solar collector was added to the south facing roof of a 14 trailer drying shed. Construction began in 1981 and was completed in 1982. This report gives information on the construction and operation of the retrofitted demonstration unit on the Carlton Butler farm in southeast Virginia.

The development and testing of the solar assist crop dryer was supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with the farm cooperator.

THE FARM

The Isle of Wight County farm is located just over 4 miles northeast of Franklin on county road 630, 1/2 mile west of its intersection with U.S. highway 258. Table 1 gives a summary of crops produced and energy required to dry these crops.

Table 1. Drying Energy

Crop	Acres	Yield	Moisture Reduction	Drying Period	Energy Required Million BTU's
Corn	160	16,000 bu.	25-15%	late Aug.-Sept.	172.8
Peanuts	210	800,000 lbs.	30-10%	late Sept.-Oct.	480.0
Soybeans	70	2,100 bu.	16-12%	Nov.	11.8
Wheat	70	3,850 bu.	16-13%	June	16.2

Interest in adding a solar collector to existing facilities was based primarily on reducing the cost of drying peanuts. An existing 48' x 105' fourteen trailer drying shed was proposed to be retrofitted for solar assist crop drying. The ridge line of the building was oriented S 75° E and two drying arrangements were sheltered which included a 10 HP LP gas drying unit for 6 trailers and two 7 1/2 HP LP gas drying units for 8 trailers. The crops which might be dried in the facility require an estimated 680.8 million BTU's annually or the equivalent of 7,654 gallons of LP gas (90,000 BTU's/gal.).

OBJECTIVES

- Provide a practical and economically feasible solar collector to preheat air for an existing trailer drying facility.

- Investigate the potential for solar collection by adding a fiberglass cover over a metal roof and plywood under the rafters to retrofit an existing structure with a suspended plate collector.

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, and September 30, 1977, in cooperation with the U. S. Department of Agriculture. Mitchell R. Geasler, Interim Dean, Extension Division, Cooperative Extension Service, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061; M. C. Harding, Sr., Administrator, 1890 Extension Program, Virginia State University, Petersburg, Virginia 23803.

SYSTEM DESIGN

The pole structure used to house the two trailer drying arrangements is typical of that constructed 10 to 20 years ago with poles interspersed to support the roof. The roof drip is over the trailer entrance area. The crop drying fan unit for the six trailer arrangement is located on the east end of the structure and the two fan units for the eight trailer arrangement located near the center of the building.

Plans were to construct two solar collectors on the roof facing S 15° W. A suspended plate collector serving the 8 trailer arrangement was constructed on the 25' x 60' roof. Another suspended plate collector serving the 6 trailer arrangement was planned for the adjacent 25' x 45' roof. By placing corrugated fiberglass over the existing metal roof and attaching plywood under the rafters, a suspended plate collector was established. The clear corrugated fiberglass treated for ultraviolet light (minimum wt. 5 ounces per sq. ft.) was attached to purlins 16" o.c. The purlins were made by nailing a 1" x 4" piece to a 2" x 4" and then nailing the inverted "T" to the existing metal roof which was painted flat black. Exterior grade 3/8" plywood was nailed under the 2" x 6" rafters 4' o.c. on the S 15° W facing roof slope completing the suspended plate collector. The plywood was partly supported by 1" x 2" furring strips underneath the rafters. The triangular air channel running under and parallel to the roof ridge was constructed by nailing 3/8" exterior grade plywood under the horizontal support member existing in the drying shed. A vertical 4' x 16' plywood plenum was constructed at the south end of the collector to duct the air into the fan entrance.

The inlet to the air channel between the plywood and the metal roof is located at the eaves. This air is drawn up the slope and into the triangular channel running just under the roof ridge. The inlet to the air channel between the fiberglass cover plate and the metal roof is located along the roof line at the western end of the collector. This preheated air, drawn parallel to the ridge line, mixes with the air from the triangular duct in a chamber above the fan entrance. From this chamber the preheated air is drawn down through the duct to the fan entrance.

The air velocity through the suspended plate is designed at 500 to 800 feet per minute. Uniform airflow through the collector was achieved by throttling the inlets. Each 7 1/2 HP 42" fan moves 25,000 cfm at 1" s.p. (mfg. rating). The 10 HP 42" fan on the proposed 6 trailer arrangement moves 27,500 cfm at 1" s.p. (mfg. ratings). This system contains no thermal insulation or other arrangement for heat storage other than those inherent in the construction materials.

The average solar radiation received at the total solar collection area serving the 14 trailer facility ranges from 5.34 to 2.68 million BTU's/day for the months of June through November, respectively. Estimating a 50 percent efficiency for a suspended plate collector, a total of 2.67 to 1.34 million BTU's/day, potentially replacing 29.7 to 14.9 gallons of LP gas daily, is available. If 75 percent of the solar energy available is utilized during early June and September through mid-November, fossil fuel required is reduced by 19 percent. This suggests an annual savings of 1,449 gallons of LP gas.

COST

The total cost, including labor, for all retrofitting and construction related to the installation of a solar collector for the 14 trailer drying structure was $4,714.50. The cost for this 2,625 sq. ft. suspended plate collector was $1.80 per sq. ft.

PERFORMANCE

The retrofitted collector over the 8 trailer unit was only partly constructed in 1981 due to loss in shipment of fiberglass. The unit was used for the first time in 1982 to assist in drying approximately 7,500 cwt of peanuts and 10,000 bushels of corn. The farmer reported close to 4,000 gal. of LP gas used to dry both crops as compared with a calculated need of 5,094 gal. of LP gas. Approximately 306 gal. of LP gas was saved drying corn and 788 gal. saved drying peanuts.

Data was collected for two periods (Oct. 6-13 and Oct. 16-21) when drying peanuts. Temperature rise above ambient was 5 to 7°F at the top of plate and 2 to 4°F above ambient at the bottom on sunny days. At 67 cents per gal. for LP gas, the fuel cost was 6.7 cents per bu. for corn drying and 26.8 cents per cwt. for drying peanuts.

ECONOMIC ANALYSIS

Based on the data collected when drying peanuts in the 8 trailer unit and estimates provided by the cooperator, the system is cost effective with or without tax credits. The assumptions made were that: the collector has a 15 year life, the annual interest on investment is 12%, and the inflation rate will be 6% annually. The present value of the 15 year investment is $8,679.87. The payback period for the project when totally constructed is 5.5 years with tax credits and 7.3 years without tax credits. Use of the trailer system for both corn and peanut drying helps make it economically attractive even though fuel was purchased at a cost of 16% less than at most other locations.

Table 2. Economic Analysis of Solar Project.

Total Energy Used: 4,000 gals.
Total Energy Saved: 1,094 gals.
Percent Savings: 21.5

Cost of Collector: $4,714.50
Cost of LPG/Gal.: $.67

Payback w/Tax Credits: 5.5 yrs.
Payback w/o Tax Credits: 7.3 yrs.

Yearly Taxes and Insurance: $94.29
Annual Maintenance Cost: $94.29
Inflation Rate: 6%

Present Value of Energy Savings
Based on 12% Interest

Year	LPG Price	Present Value
1	$ .67	$ 654.47
2	.73	642.76
3	.81	631.29
4	.89	619.99
5	.98	608.90
6	1.07	598.02
7	1.18	587.44
8	1.30	576.91
9	1.43	566.57
10	1.57	556.52
11	1.73	546.58
12	1.91	536.83
13	2.10	527.25
14	2.31	517.72
15	2.54	508.54

Net Present Value for 15 Years: $8,679.87

System is cost effective w/tax credits.
System is cost effective w/o tax credits.

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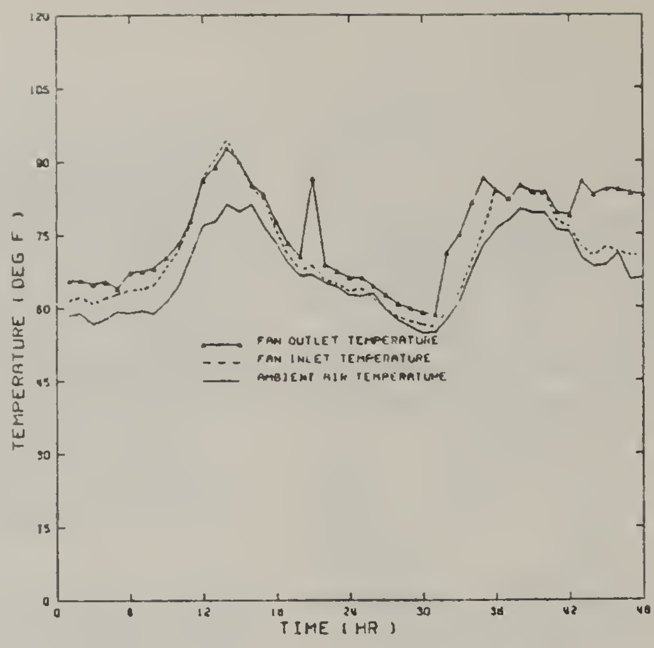
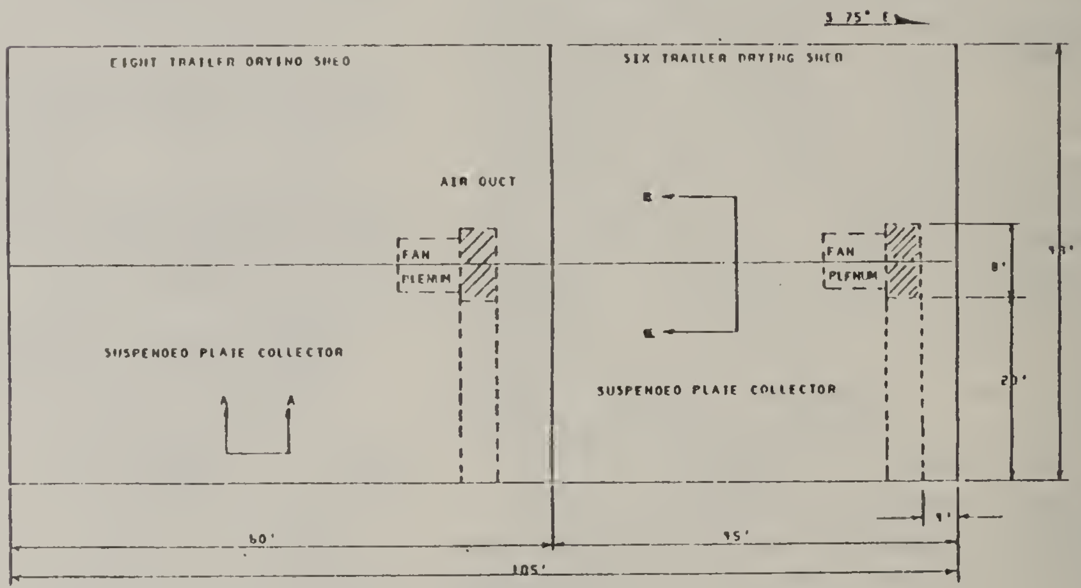
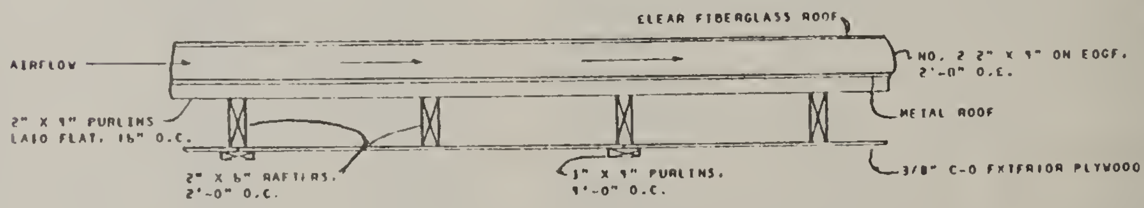


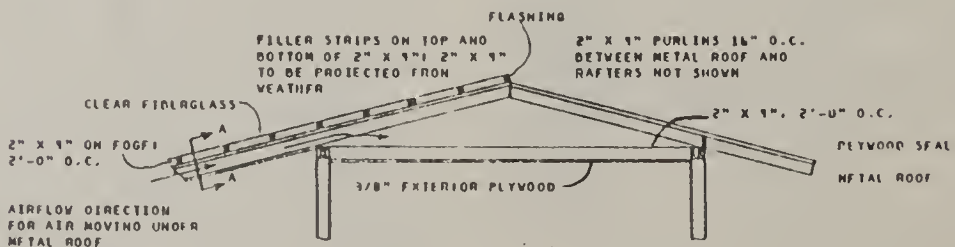
PERFORMANCE DATA FOR CARLTON BUTLERS SOLAR COLLECTOR



TOP VIEW OF PEANUT DRYING FACILITY



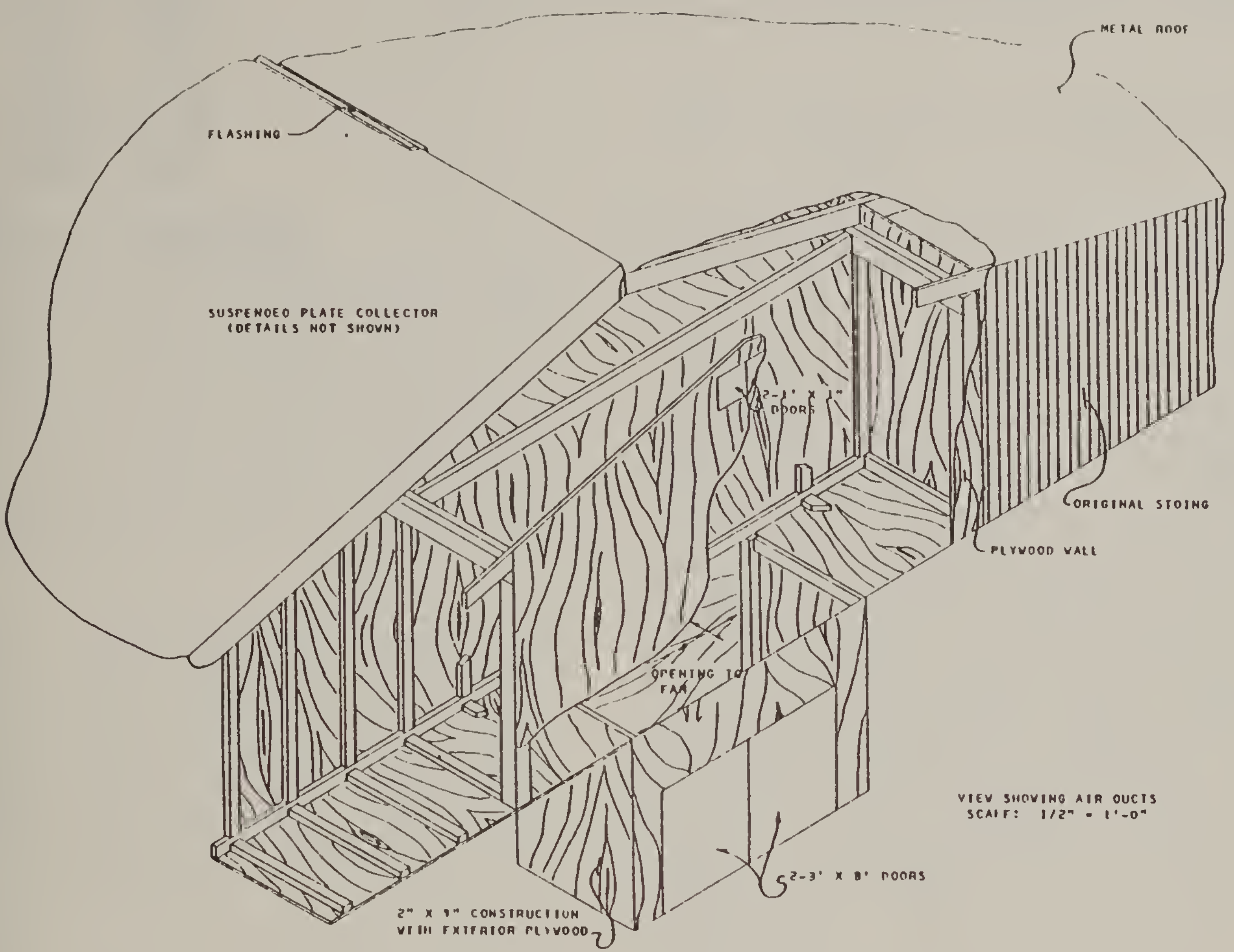
SECTION A-A



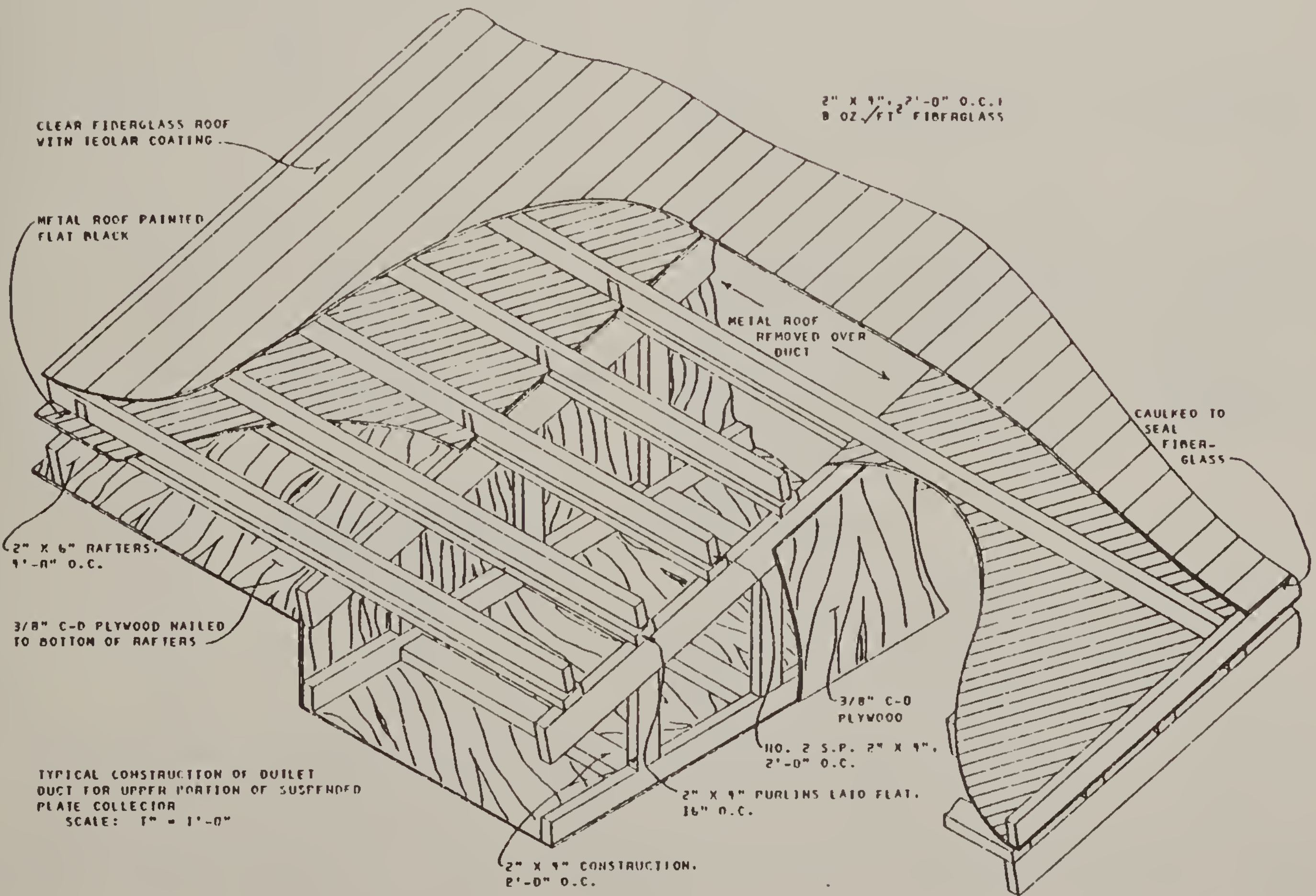
SECTION C-C

DRYING CAPACITY: 14 TRAILERS
8 TRAILERS DRIED WITH 2-7 1/2 HP FANS
6 TRAILERS DRIED WITH 1-10 HP FAN
ROOF SLOPE OF SHEDS: 3/12
AREA OF PROPOSED SUSPENDED PLATE COLLECTOR: 2625 FT^2

8 518



VIEW SHOWING AIR DUCTS
SCALE: 1/2" = 1'-0"



TYPICAL CONSTRUCTION OF OUTLET DUCT FOR UPPER PORTION OF SUSPENDED PLATE COLLECTOR
SCALE: 1" = 1'-0"

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SOLAR CROP DRYING SERIES

Agricultural Engineering

Solar Crop Drying in Retrofitted Twelve Trailer Shed

A. J. Lambert and J. P. Harner, III

A solar collector was added to an existing 6 trailer half of a 12 trailer crop drying arrangement in 1981. The other 6 trailer unit was retrofitted with a solar collector in 1982. This report gives information on the construction and operation of the demonstration unit on the John T. Butler, Jr. farm.

The development and testing of the retrofitted solar assist dryers supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with the farm cooperator.

THE FARM

The southeast Virginia farm is located 6 miles southeast of Isle of Wight County Courthouse on county road 600 1.5 miles northeast from its intersection with county road 637. Table 1 gives a summary of crops produced and energy required to dry these crops.

Table 1. Drying Energy.

Crops	Acres	Yield
Corn	100	10,000 bu.
Peanuts	60	180,000 lbs.
Soybeans	20	700 bu.
Small Grain	20	

Crop	Drying Period	Energy Required Million BTU's
Corn	Sept.	108.0
Peanuts	Oct.	108.0
Soybeans	Nov.	3.9
Small Grain	June	Usually None

Interest in adding a solar collector to existing facilities was based primarily on reducing the cost of drying peanuts. The cooperator also custom dries peanuts for other farmers in these and other facilities. An existing 46'-6" x 60' pole structure equipped for drying in two 6 trailer drying units, with crop drying fans at each end, was proposed to be retrofitted for solar assist drying. The building ridge line runs S 43° E. The crops which are dried in the facility require an estimated 219.9 million BTU's annually or the equivalent of 2,443 gallons of LP gas (90,000 BTU's/gal.).

OBJECTIVES

- Provide a practical and economically feasible solar collector to preheat air for an existing trailer drying facility.
- Compare the operation of a bare plate, covered plate and suspended plate collectors on the same structure.
- Investigate the potential for solar collection by adding a fiberglass cover over a metal roof and plywood under the rafters to retrofit an existing structure with a suspended plate collector with non-optimal orientation.

SYSTEM DESIGN

The pole structure used to house the two 6 trailer drying systems is typical of that employed nearly 20 years ago. The roof structure is supported by poles 10' apart

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throughout the length of the building and 14' apart perpendicular to the main plenum.

Two solar collectors were constructed, each serving separate fans located at opposite ends of this trailer drying facility. The fan on the southeast end of the drying shed is supplied, in part, by air passing through a 28' x 25' suspended plate collector (on the roof slope facing S 47° W). The remainder of the airflow passes through a 30' x 25' bare plate collector under the roof facing N 47° E. The airflow then mixes and passes through a 16' x 11' covered plate collector over the fan housing roof and through a vertical 16' x 8' covered plate collector (facing S 43° E) before entering the fan. A similar air collector was constructed for the northwest end of the drying shed; however, after air passes through the roof collector it is channeled through a plywood duct to the fan entrance.

The main portion of the solar collector is constructed on the roof of the existing drying shed. On the roof slope facing S 47° W the suspended plate was constructed by placing corrugated fiberglass over the existing metal roof and attaching plywood under the rafters. A bare plate collector was constructed on the roof slope facing N 47° E by attaching plywood under the rafters. The inlet to the air channel between the plywood and the metal roof is located at the eaves. The air is drawn up the slope and into a large triangular channel running just under and parallel to the roof ridge. The drying fan draws the air through the triangular channel towards the fan entrance.

The inlet to the air channel between the fiberglass cover plate and the metal roof is located along the roof line under the fiberglass halfway between ends of the drying shed where air is drawn from below the roof inside the drying shed. This preheated air is also directed to the fan entrances through a 4' wide duct at each end of the drying shed where it is drawn into the drying units and forced into the plenums and through the drying trailers.

The air velocity through the suspended plate and bare plate collectors varies from 500 to 800 feet per minute. This solar collector functions only when a fan is in operation. The drying shed is equipped with two (one for each 6 trailer unit) 7 1/2 HP 42" fans which move 23,000 cfm at 1" s.p. (mfg. ratings). This system contains no thermal insulation or arrangement for heat storage other than that inherent in the construction materials.

The average solar radiation received at the total solar collection area serving the southeast fan ranges from 2.04 to 1.31 million BTU's/day for the months of September through November, respectively. The solar collection area which serves the northwest fan receives 1.64 to 1.03 million BTU's/day during this same time period, assuming the northeast roof slope receives 50 percent as much solar radiation as that striking the southwest roof slope. Efficiencies of 25, 40, and 50 percent are estimated for the bare plate, covered plate, and suspended plate collectors, respectively. Accordingly, 0.84 to 0.54 million BTU's/day and 0.68 to 0.43 million BTU's/day will be available to preheat the drying air at the southeast and northwest fans, respectively. A total of 1.52 to 0.97 million BTU's/day potentially replacing 16.9 to 10.8 gallons of LP gas daily is available in the fall drying season. If 50 percent of the solar energy available is utilized, fossil fuel required is reduced by 22 percent. This suggests an annual savings of 544 gallons of LP gas. Any benefit from solar heat to aid in the custom drying of area farmers crops was not included.

COST

The total cost, including labor, for all construction related to installation of solar collectors on this 12 trailer structure was $4,599.19. The cost per sq. ft. of collector surface for 3,204 sq. ft. was $1.44.

PERFORMANCE

Construction of one add-on solar collector for a 6 trailer drying unit was completed in 1981 and the second unit completed in 1982. Information on the use of the facility relates only to peanut drying. Some data was obtained on the operation of the first retrofitted unit in both 1981 and 1982. Other information was provided by the cooperator. Typical performance data for a 42 hour period in 1981 is shown in Figure 1. The difference between ambient air and fan inlet air temperature is an indication of the amount of energy contributed by solar and recovered in the system. Data for 1982 was recorded on a strip chart and has not been processed.

ECONOMIC ANALYSIS

Based on the data collected and other information supplied by the farmer along with certain assumptions, the solar collector system is cost effective with or without tax credits (Table 2). Use of the facility for custom drying was not included in this analysis. The assumptions are: the collector has a 15 year life, the annual inflation rate will be 6%, and the interest on the investment is 12% annually. The present value of the 15 year investment is $7,578.82. The payback period is 6.3 years with tax credits and 8.4 years without tax credits.

Table 2. Economic Analysis of Solar Project.

Total Energy Used: 1,643 gals.
Total Energy Saved: 800 gals.
Percent Savings: 32.7%

Cost of Collector: $4,599.19
Cost of LPG/Gal.: $.80

Payback w/Tax Credits: 6.29 yrs.
Payback w/o Tax Credits: 8.39 yrs.

Yearly Taxes and Insurance: $91.98
Annual Maintenance Cost: $91.98
Inflation Rate: 6%

Present Value of Energy Savings
Based on 12% Interest

Year	LPG Price	Present Value
1	$ .80	$ 571.45
2	.88	561.22
3	.96	551.21
4	1.06	541.34
5	1.17	531.66
6	1.28	522.16
7	1.41	512.93
8	1.55	503.73
9	1.71	494.70
10	1.88	485.92
11	2.07	477.24
12	2.28	468.73
13	2.51	460.36
14	2.76	452.05
15	3.03	444.03

Net Present Value for 15 Years: $7,578.82

System is cost effective w/tax credits.
System is cost effective w/o Tax credits.

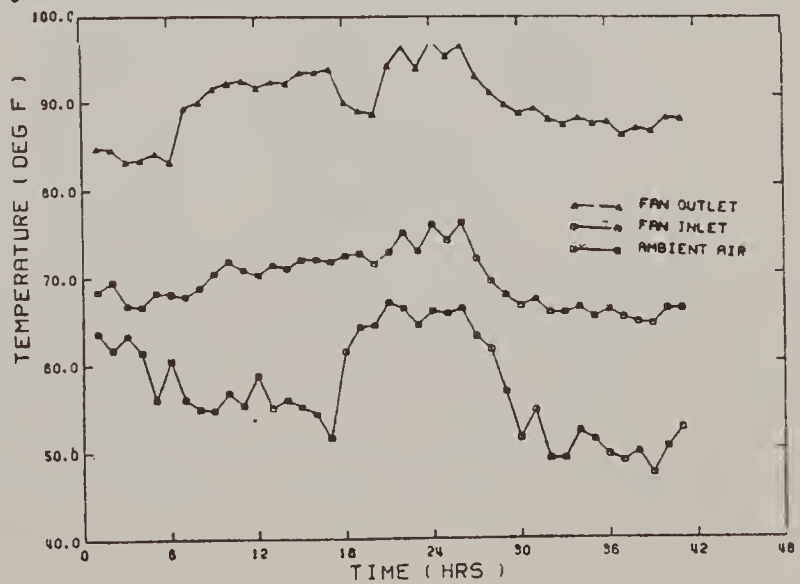
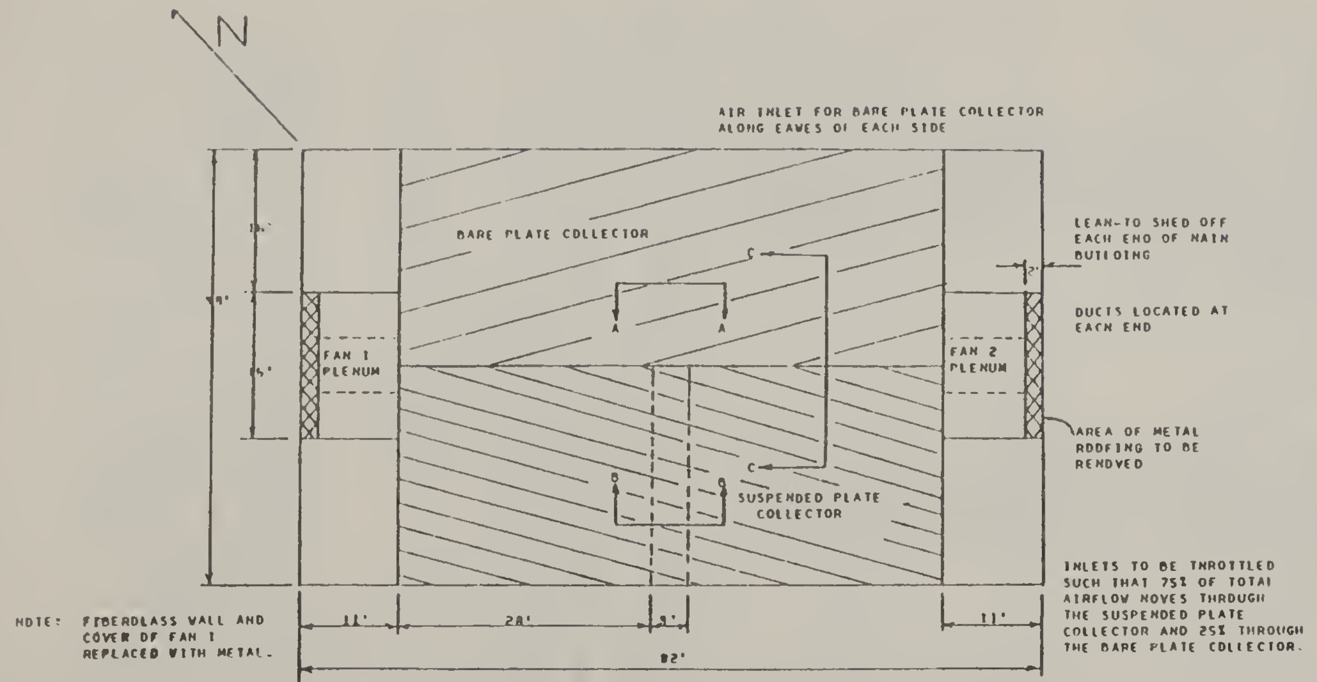


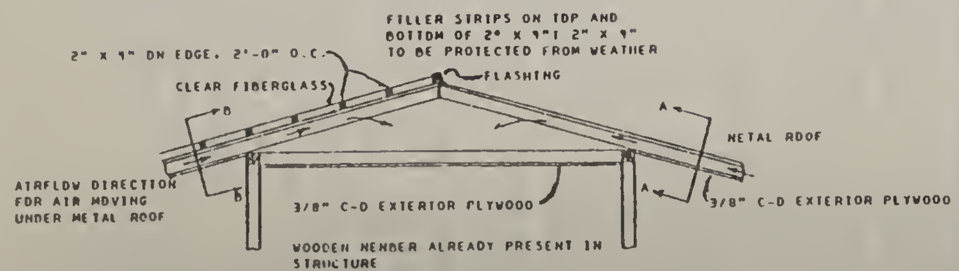
Figure 1. Typical performance curves, Fall, 1981.



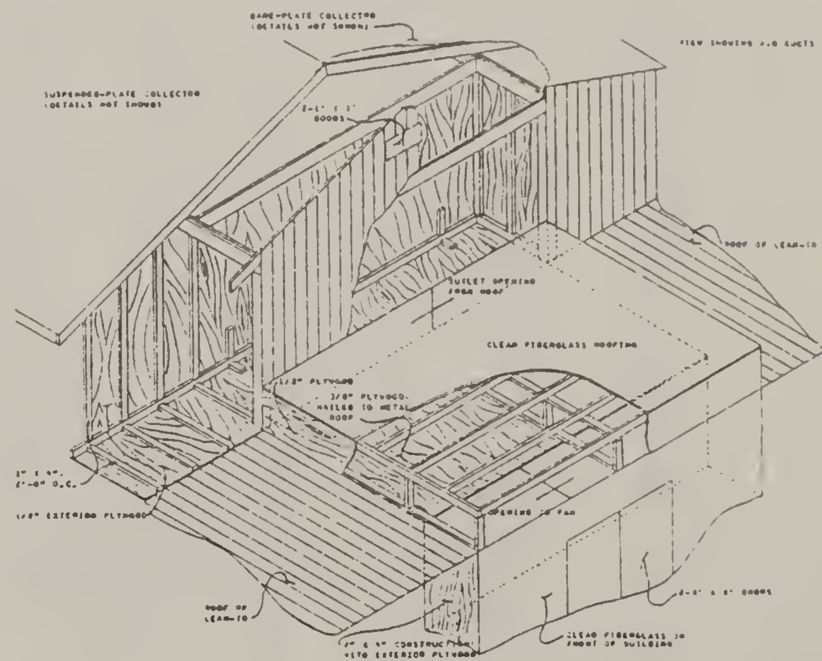
TOP VIEW OF PEANUT DRYING FACILITY

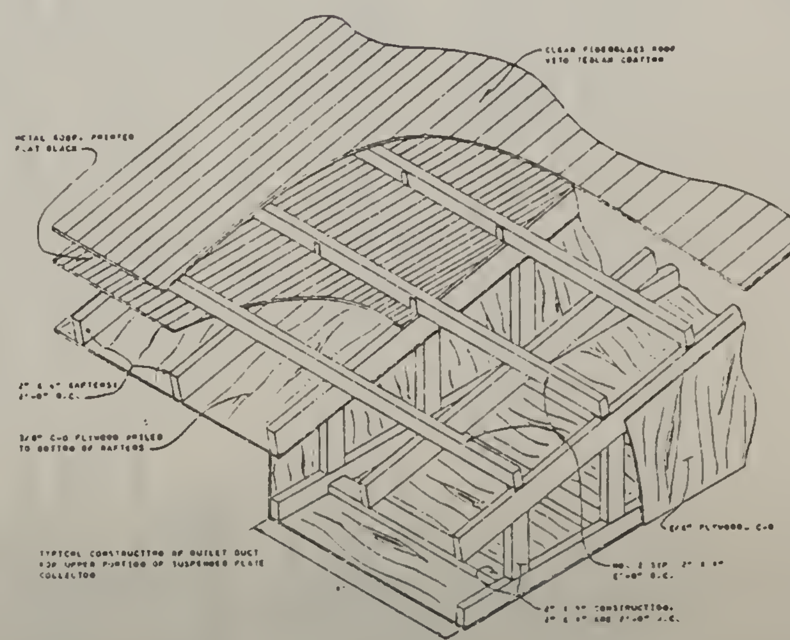
SECTION A-A

SECTION B-B



SECTION C-C





DRYING CAPACITY: 12 TRAILERS
2 FANS, EACH 7 1/2 HP
ROOF SLOPE ON MAIN SHED: 3/12
ROOF SLOPE ON LEAN-TO: 1/12
AREA OF PROPOSED BARE PLATE COLLECTOR: 1500 FT^2
AREA OF PROPOSED SUSPENDED PLATE COLLECTOR: 1500 FT^2

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SOLAR CROP DRYING SERIES

Agricultural Engineering

Add-On Greenhouse and Solar Crop Drying in Retrofitted Six Trailer Crop Drying Shed

A. J. Lambert and J. P. Harner, III

An existing six trailer crop dryer in a poletype shed was retrofitted to include a solar collector for demonstration on a Southeast Virginia farm in 1981. The collector was added to provide solar energy to assist with grain drying and peanut curing. This report gives information on the construction and operation of the collector on the John S. Copeland farm.

The development and testing of the solar assist dryer was supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with the farm cooperator.

THE FARM

The Copeland farm is located approximately 2 miles southwest of Windsor on Isle of Wight County road 609 one mile southeast of U.S. Highway 258. Crops grown on this farm include 62 acres of corn, 41 acres of peanuts, and 20 acres of soybeans. Approximately 7750 bushels of corn are dried during August and September. The 164,000 pound peanut crop is dried in October followed by 700 bushels of soybeans in early November. The energy required to dry these crops is estimated at 83.7 million BTU's for corn, 98.4 million BTU's for peanuts, and 3.9 million BTU's for soybeans. The total energy needed is 186 million BTU's or the equivalent of 2067 gallons of LP gas (90,000 BTU/gal.).

Prior to the installation of the solar collector, grain and peanuts were dried in an 18 ft. diameter 2000 bu. bin equipped with a 5 HP crop dryer unit and in 4 trailers in a pole type 6 trailer shed equipped with a 7 1/2 HP crop drying unit. The ridge of the roof on the pole shed runs South 14° West.

OBJECTIVES

- Provide a practical and economically feasible solar collector to preheat air for an existing trailer drying facility.
- Investigate the potential for increased savings through the addition of a south facing solid metal absorber with airflow on both sides.
- Investigate the potential for solar collection by adding a fiberglass cover over a metal roof absorber with non-optimum orientation.

SYSTEM DESIGN

The cooperator decided to construct a 640 sq. ft. greenhouse on the southwest end of the 40 ft. by 42 ft. pole type drying shed to serve as an air collection area for solar drying and for plant producton. Both sides of the shed roof were oriented at angles less than optimum for solar collecting surfaces. However, a covered plate roof collector consisting of the two 1012 ft^2 roof slopes at a 1/3 pitch facing N 76° W and S 76° E, respectively, could be installed on these sides. The attached integrated greenhouse contributes 720 ft.^{2} of roof sloping 27° toward south 14° west. a 160 ft^2

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vertical wall facing in the same direction and two 128 ft^2 endwalls. A total of 3160 ft^2 of solar collector surface is utilized much of which is not optimally oriented.

The average radiation on the total solar collection surface areas from August through November is projected at 5.12 to 2.63 million BTU's/day, respectively. Anticipating a 40% efficiency for this combination covered plate-integrated shed solar collector, 2.05 to 1.05 million BTU's per day should be available to preheat the drying air, potentially replacing 22.8 to 11.7 gallons of LP gas daily. If 50% of the solar energy available is utilized, fossil fuel required to dry the crops on this farm can be reduced by 38% for an annual savings of 787 gallons of LP gas.

Table 1. Solar Insolation.

Norfolk, VA - 36^{o} 54' N. Latitude used as reference

Copeland - Windsor, VA - 36^{o} 45' N. Latitude

Slope: 18' x 40', 27^{o}, 720 ft^2

Wall: 4' x 40', 90^{o}, 160 ft^2

Endwalls: 2-16' x 8', 90^{o}, 256 ft^2

Roof: 23' x 44', 18.5^{o}, 1,012 ft^2 (N 76^{o} W)
23' x 44', 18.5^{o}, 1,012 ft^2 (S 76^{o} E)

Million BTU's/day

	July	August	Sept.
Slope	1.36	1.27	1.17
Wall	0.13	0.14	0.17
Endwalls	0.32	0.32	0.27
Roof	1.97/	1.77/	1.59/
	1.92	1.62	1.21
	(3.89)	(3.39)	(2.80)
TOTAL	5.70	5.12	4.41
40%	2.28	2.05	1.76
Gals. LPG/day	25.3	22.8	19.6

Million BTU's/day

	Oct.	Nov.	Dec.
Slope	1.04	0.85	0.74
Wall	0.19	0.19	0.18
Endwalls	0.23	0.18	0.13
Roof	1.16/	0.86/	0.68/
	0.91	0.56	0.38
	(2.07)	(1.41)	(1.06)
TOTAL	3.53	2.63	2.11
40%	1.41	1.05	0.84
Gals. LPG/day	15.7	11.7	9.3

The solar collector covers the entire roof of the drying shed in addition to the roof and outside walls of the attached greenhouse. A cover plate of clear corrugated fiberglass treated for ultraviolet light (minimum 5 ounces per ft^2) along with the existing metal roof, painted flat black, acts as the absorber and functions as the main components of the collector on the roof of the drying shed. The outer surfaces of the attached greenhouse make use of the same type fiberglass. The vertical absorber on the interior wall is horizontally corrugated metal, painted black, which extends down to 6 inches from the groundline and is approximately 4 inches inside of a 3/8 inch (exterior grade) plywood wall.

The air inlet is located at the north end of the roof collector, where ambient air is drawn from outside the drying shed. This air receives heat from the absorber as it is drawn parallel to the ridge line by the fan in the drying unit. When reaching the integrated shed, the airflow is

channeled down between the metal absorber and the plywood wall and then into the collection area. The preheated air passing through the drying unit is forced into the plenum and through the drying trailers.

The air velocity through the roof collector and between the vertical metal absorber and plywood wall varied from 150 to 500 feet per minute. An additional inlet in the vertical plywood wall permits the remaining airflow required by the drying unit to enter the collection area from inside the drying shed.

This solar collector functions to assist with drying whenever solar energy is available and the fan is in operation. There is no thermal insulation or arrangement for heat storage, other than that inherent in the construction materials. Approximately 20,300 cfm (mfg. fan rating) of air is moved through the collectors.

COST

The total cost, including labor, for the 3160 sq. ft. of covered plate collector and associated solar greenhouse air collection area was $3830.41 or $1.22 per sq. ft. of collector surface.

PERFORMANCE

Construction of the add-on solar assist facility was nearly complete for use with crop drying in the fall of 1981. In September, 4262 bushels of corn were dried from approximately 25% to 13% moisture content. In October, 156,928 pounds of peanuts were dried.

Data were collected on drying corn in 1982 from September 7 to 22. During this period, 4250 bushels were dried from 23.2% to 12.8% moisture content. Four batches including 17 trailer loads of corn were dried using 734 gallons of LP gas and a solar equivalent of 260 gallons of LP gas during the 15 day period. Of the heat used for drying, an average of 26% came from solar with a range of 20 to 35% for the four batches. When comparing the average temperature difference between ambient and fan inlet with that between fan inlet and outlet, 23.3% of the heat gain was supplied from sources other than fuel and electric energy used to operate the fan during this 15 day period.

It is estimated that the equivalent of 523 gallons of LP gas was saved in drying of 157,000 pounds of peanuts in 1982. Total energy savings were estimated at 800 gallons of LP gas.

ECONOMIC ANALYSIS

Based on the data collected and other information supplied by the farmer along with certain assumptions, the solar collector system is cost effective with or without tax credits. The assumptions are: the collector has a 15 year life, the annual inflation rate will be 6%, and the interest on the investment is 12% annually. The present value of the 15 year investment is $7,578.82. The payback period is 5.1 years with tax credits and 6.8 years without tax credits.

Table 2. Economic Analysis of Solar Project.

Total Energy Used: 1,267 gals.
Total Energy Saved: 800 gals.
Percent Savings: 38.7

Cost of Collector: $3,830.41
Cost of LPG/gal.: $.80

Payback w/Tax Credits: 5.1 yrs.
Payback w/o Tax Credits: 6.8 yrs.

Yearly Taxes and Insurance: $76.60
Annual Maintenance Cost: $76.60
Inflation Rate: 6%

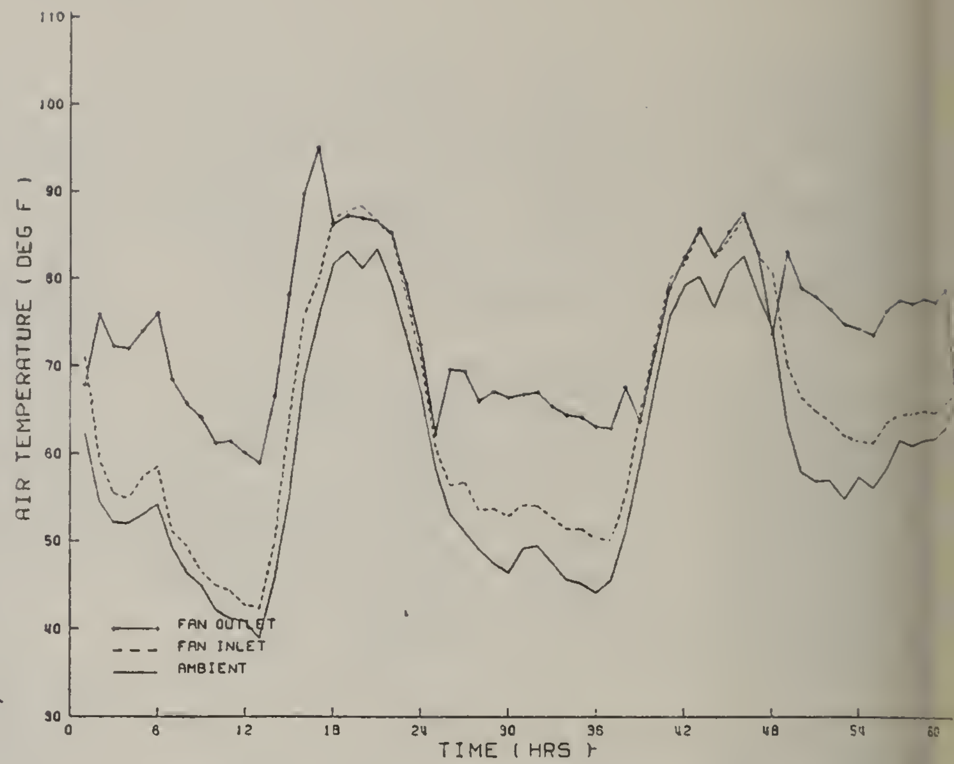
Table 2 (continued)

Present Value of Energy Savings
Based on 12% Interest

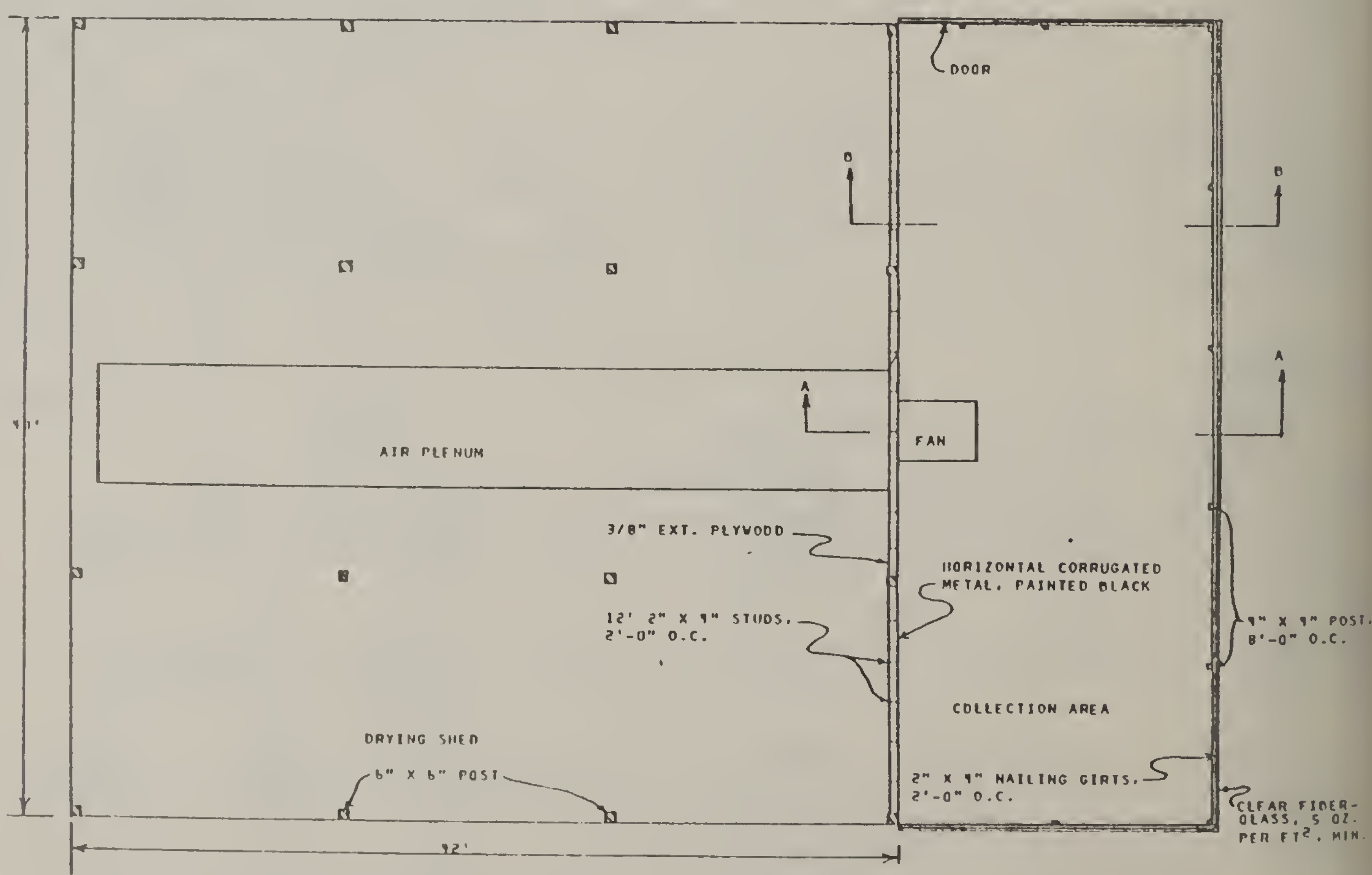
Year	LPG Price	Present Value
1	.80	$ 571.46
2	.88	561.23
3	.97	551.22
4	1.06	541.34
5	1.17	531.67
6	1.29	522.16
7	1.42	512.93
8	1.56	503.73
9	1.71	494.71
10	1.89	485.93
11	2.07	477.25
12	2.28	468.73
13	2.51	460.37
14	2.76	452.05
15	3.03	444.33

New Present Value for 15 Years:
$7,578.82

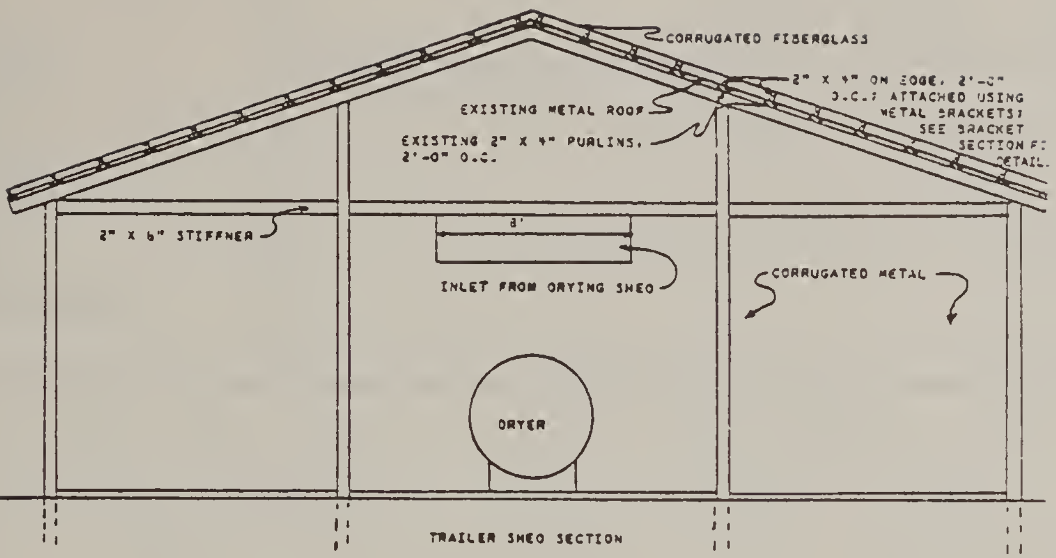
System is cost effective w/tax credits.
System is cost effective w/o tax credits.



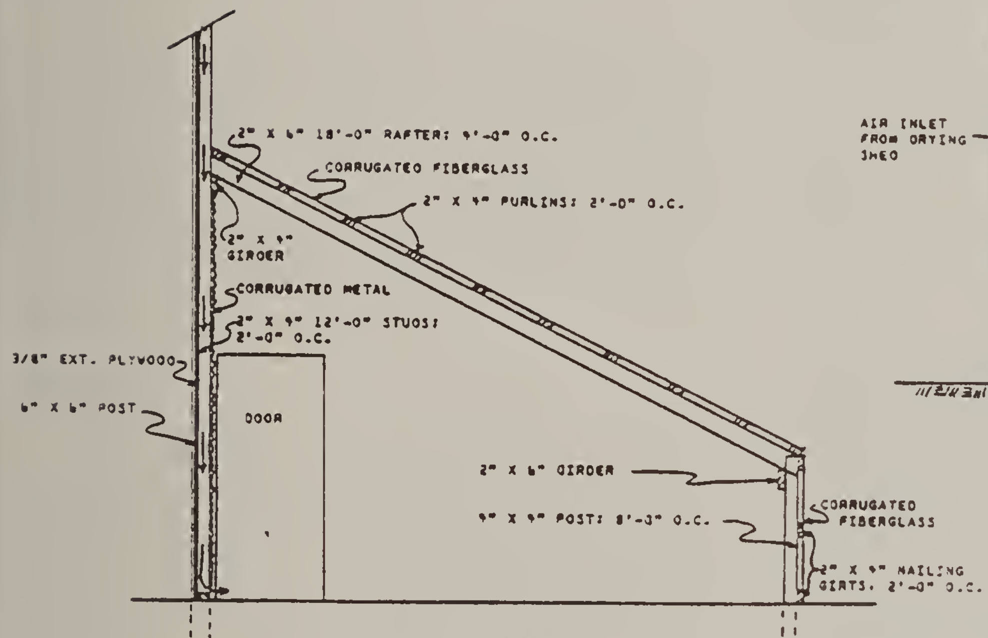
PERFORMANCE DATA FOR COPELANDS SOLAR (1981)



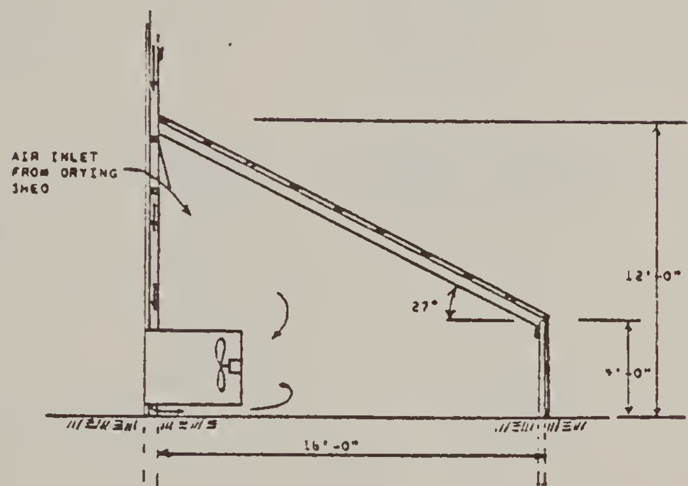
FLOOR PLAN



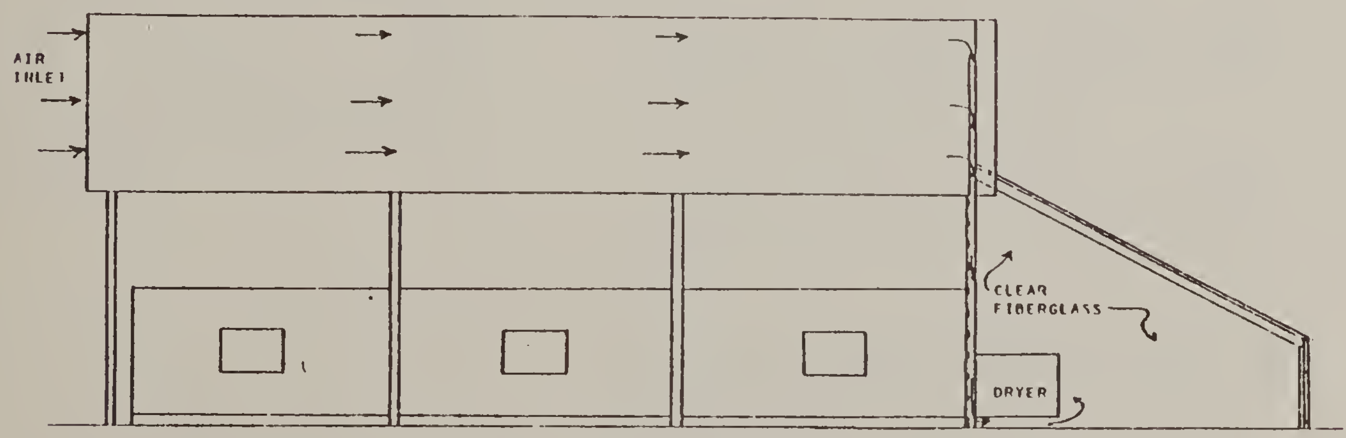
TRAILER SHED SECTION



SECTION B-B



SECTION A-A



SIDE VIEW

SOLAR CROP DRYING SERIES

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Agricultural Engineering

Solar Crop Drying in Six Trailer Shed (Drewry Farm)

A. J. Lambert and J. P. Harner, III

A new six trailer solar crop dryer was constructed on a southeast Virginia farm in 1981 to dry grain and peanuts. This report gives information on the construction and operation of the demonstration unit on the Michael Drewry farm.

The development and testing of the solar assist dryer was supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with the farm cooperator.

THE FARM

The Drewry farm is located on the Sussex-Surry County line 3 miles north of Wakefield at the intersection of State Road 31 and County Road 629. Table 1 lists the crops grown on the farm which could require energy for drying.

The farm has been in operation only six years and needed additional drying capacity. Previously, crops were dried in one 18' diameter metal bin and by custom dryers. It was estimated that a total of 229.2 million BTU's, equivalent to 2,547 gallons of LP gas (90,000 BTU/gal.) were needed annually to dry the crops produced on this farm.

Table 1. Drying Energy

Crops	Acres	Yield
Peanuts	65	227,500 lbs.
Corn	80	6,800 bu.
Soybeans	85	2,550 bu.
Milo	10	500 bu.
Sunflower	5	7,500 lbs.

Crops	Drying Period	Energy Required Million BTU's
Peanuts	late Sept.-Oct.	136.5
Corn	late Aug.-Sept.	73.4
Soybeans	Nov.	14.3
Milo	Nov.	
Sunflower	mid-July, Nov.	5

OBJECTIVES

- Provide a practical and economically feasible solar collector to preheat air for a trailer drying operation.
- Determine the value of utilizing an expanded metal lathing as an additional absorber.
- Investigate the potential for increased savings through the addition of a solid metal absorber with airflow on both sides.
- Analyze the productivity of a solar collector utilized for an extended drying season.
- Examine the performance of the collector while utilizing various airflow patterns into the collection area.

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SYSTEM DESIGN

The six trailer pole-type 36' x 48' drying shed with a truss roof is of typical construction used on many farms in southeast Virginia during the past several years. A 8'-2" x 48' solar greenhouse was added to the southwest side of the shed to form a solar heated air collection area. The total solar surfaces of 1,940 sq. ft. are made up by utilizing the southwest roof of the shed plus the roof and 8'-7" vertical wall of the S 27° W facing collection area. The roof collector which is at a slope of 22.6° (5/12 pitch) accounts for 1,360 sq. ft. of the total area.

A clear corrugated fiberglass cover was substituted for the metal roof normally used on the southerly slope. This cover plate, treated for ultraviolet light (minimum 5 ounce per ft^2), along with a flat black 3/8" (exterior grade) plywood absorber functions as the main components of the collector. A black metal lathing (one inch expanded to five inches) inserted between the fiberglass and the plywood was installed to perform as an additional absorber to increase collector efficiency. The cover plate on the outer walls and roof of the attached greenhouse structure were constructed using the same type fiberglass backed with a metal lathing. An additional absorber is located on the greenhouse structures interior wall. It is horizontally corrugated metal sheathing, painted black, extending down to 6" from the groundline and approximately 4" in front of a 3/8" exterior grade plywood wall. This plywood wall is interfaced with the drying shed and encloses the integrated collection shed.

The inlet for the collector is located under the ridge and draws air from the top of the shed. The air receives solar heat as it is brought down the slope of the roof by the crop drying fan. Upon reaching the integrated shed, the airflow is channeled both directly into the integrated collection area and down between the metal absorber and the plywood wall into the collection area. The preheated air is forced through the drying unit, into the plenum, and through the drying trailers. This solar collector functions whenever the fan is in operation. This system contains no thermal insulation or arrangement for heat storage other than that inherent in the construction materials.

The average radiation received at the total solar collection surface of 1,940 sq. ft. in the months of July through December ranges from 3.11 to 1.78 million BTU's/day, respectively. The solar assist crop dryer is located 36° 58' north latitude and 91% of the solar collector faces S 27° W. A 40% efficiency was anticipated for this combination covered plate integrated shed solar collector making available 1.24 to 0.71 million BTU's/day for preheating the drying air, potentially replacing 14.2 to 8.1 gallons of LP gas daily. With a 50% utilization rate solar energy was expected to reduce fossil fuel required to dry crops on this farm by 31% which results in an annual savings of 764 gallons of LP gas.

Table 2.

Norfolk, VA - 36° 54' N. Latitude used as reference

Drewry - Wakefield, VA - 36° 56' N. Latitude (facing S 27° W)

Roof: 28'-4" x 48', 22.6°, 1,360 ft^2

Wall: 8'-7" x 48', 90°, 412 ft^2

Sidewalls: $2\left\{(8'\text{-}2'' \times 8'\text{-}7'') + \frac{3'\text{-}5''}{2}\right\}$, 90°, 168 ft^2

	Million BTU's/day	
	July	August
Roof	2.64	2.43
Wall	.37	.40
Sidewall	.20	.20
TOTAL	3.21	3.03
40%	1.28	1.21
Gals. LPG/day	14.2	13.4

	Million BTU's/day	
	Sept.	Oct.
Roof	2.18	1.89
Wall	.45	.48
Sidewall	.18	.16
TOTAL	2.81	2.53
40%	1.12	1.01
Gals. LPG/day	12.4	11.2

	Million BTU's/day	
	Nov.	Dec.
Roof	1.50	1.30
Wall	.45	.43
Sidewall	.12	.10
TOTAL	2.07	1.83
40%	0.83	0.73
Gals. LPG/day	9.2	8.1

COST

The total cost, including labor, for all construction related to the solar aspects of the six trailer crop drying shed was $2,927.04 or $1.51 per sq. ft. of collector surface.

PERFORMANCE

Construction was completed in time to dry corn and peanuts in 1981. Only four trailers were purchased and used in the solar drying shed to dry approximately 2/3 of these crops. About 140,000 lbs. of peanuts were dried using 360 gals. of LP gas and 2,334 kwh of electricity at a cost of 29 cents per cwt. (6 cents/kwh and 74 cents/gal. LPG). In 1979, two years before the solar drying shed was used, the cost to dry peanuts on the farm in other facilities was 70 cents per cwt. and $1.15 per cwt. in custom drying facilities. The energy required for forced air drying is related to weather conditions during the harvesting season.

Until November, 1982, the solar drying shed was used to dry wheat, sunflower seed, corn, and peanuts. It cost 13.6 cents/bu. to dry 2,000 bu. of corn from 23 to 10% whereas it cost 21 cents/bu. to dry in a conventional grain bin. Data on energy use were collected for the period October 2-27. The crop drying fan operated 325 hrs. and the burner was on 207 hrs. during this period when drying nearly 150,000 lbs. of peanuts. The burner used 2.9 gal./hr. of LP gas when operating. It cost 45 cents per cwt. (80 cents/ gal. LPG, 7 cents/kwh) to dry in the solar shed and 60 cents per cwt. to dry in conventional metal bin.

ECONOMIC ANALYSIS

Based on the data collected and other information supplied by the farmer along with certain assumptions, the solar collector system is cost effective with or without tax credits (Table 3). The assumptions are: the collector has a 15 year life, the annual inflation rate will be 6%, and the interest on the investment is 12% annually. The present value of the 15 year investment is $7,238.72. The payback period is 4 years with tax credits and 5.3 years without tax credits.

Table 3. Economic Analysis of Solar Project

Total Energy Used: 1,782.9 gals.
Total Energy Saved: 764.1 gals.
Percent Savings: 30

Cost of Collector: $2,927.04
Cost of LPG/gal.: $.80

Payback w/tax credits: 3.97 yrs.
Payback w/o tax credits: 5.29 yrs.

Yearly tax and insurance: $58.54
Annual maintenance cost: $58.54
Inflation rate: 6%

Present Value of Energy Savings
Based on 12% Interest

Year	LPG Price	Present Value
1	.80	$ 545.81
2	.88	536.04
3	.97	526.48
4	1.06	517.05
5	1.17	507.80
6	1.28	498.73
7	1.42	489.91
8	1.56	481.13
9	1.71	472.50
10	1.89	464.12
11	2.07	455.83
12	2.28	447.70
13	2.51	439.71
14	2.76	431.77
15	3.03	424.11

Net Present Value for 15 Years: $7,238.72

System is cost effective w/tax credits.
System is cost effective w/o tax credits.

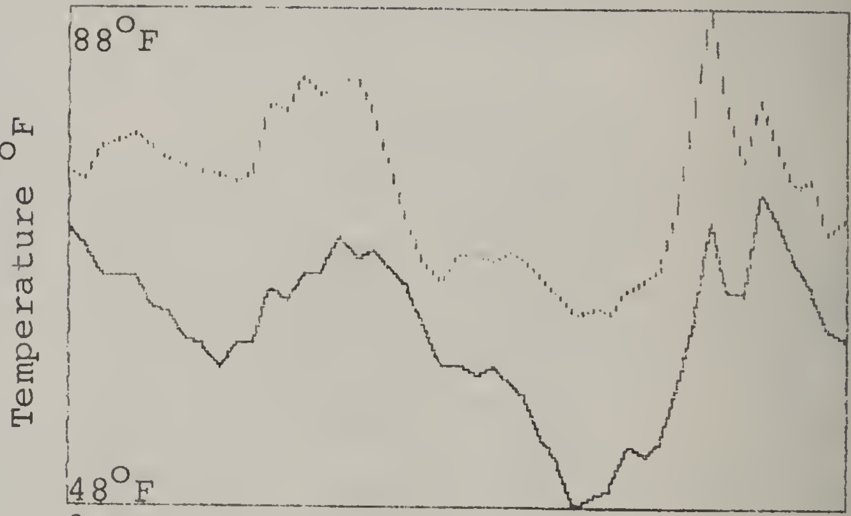
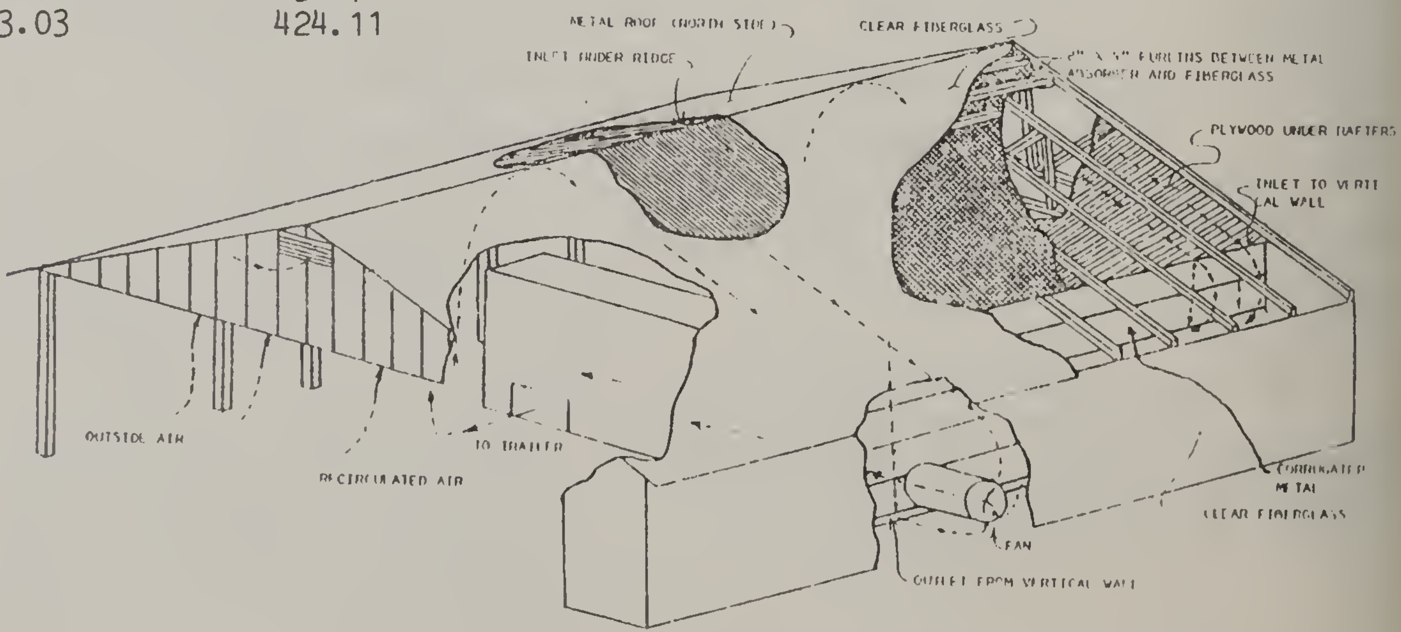
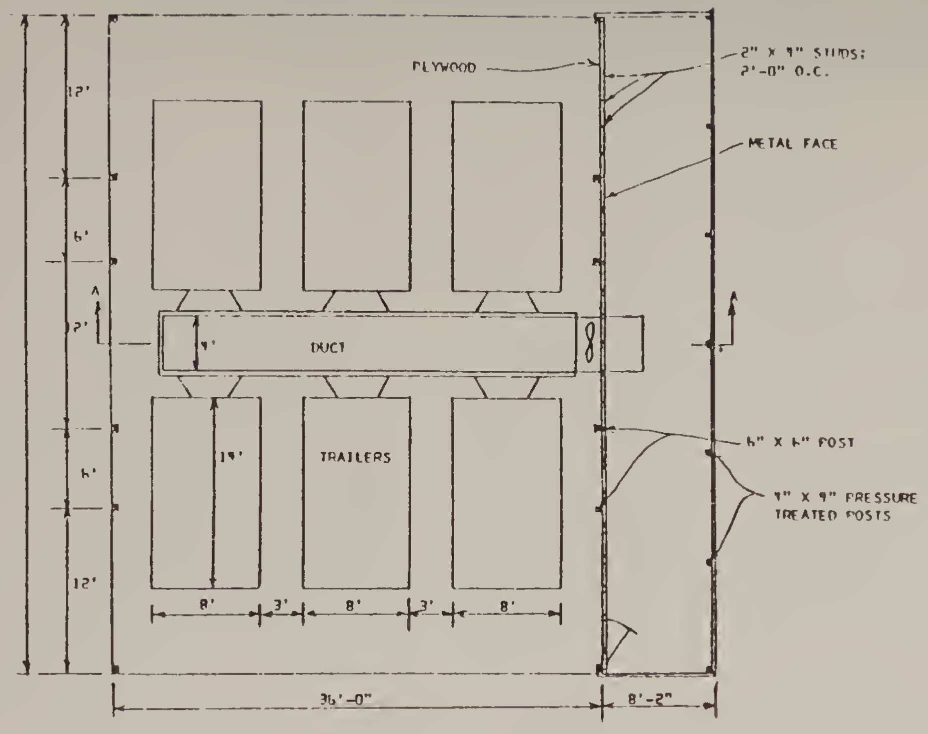
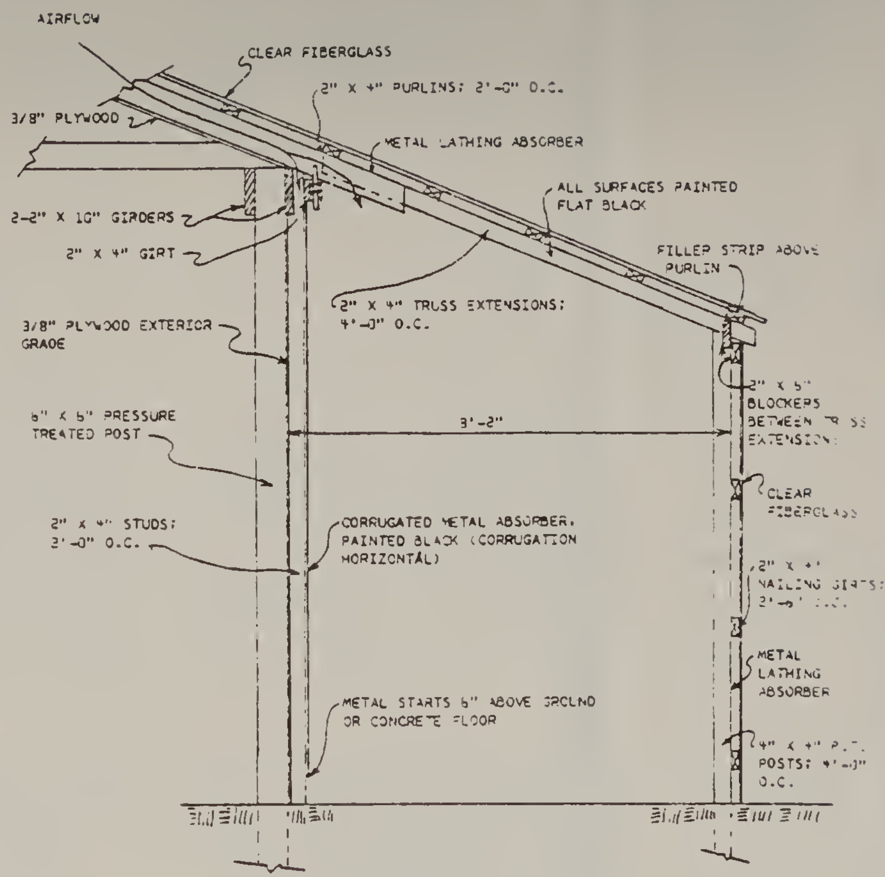


Figure 1. Fan inlet vs. ambient air.

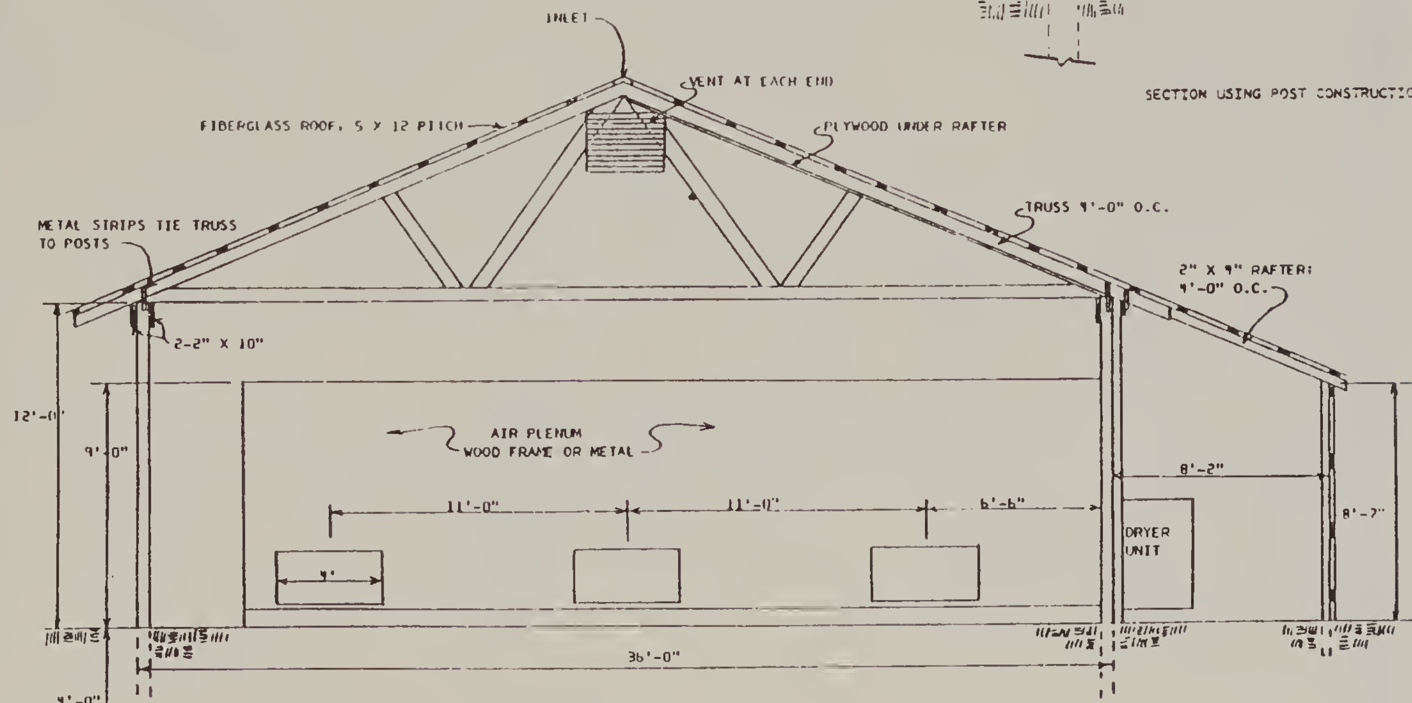




PLAN



SECTION USING POST CONSTRUCTION



SECTION A-A

FOR DETAILS SEE SECTION

SOLAR CROP DRYING SERIES

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Agricultural Engineering

Portable Solar Collector for Multi-Use and Swine House Heat Storage

A. J. Lambert and J. P. Harner, III

Demonstration of a portable solar collector to provide heat for several farm applications was initiated on a Southeast Virginia farm in 1981. The collector was designed primarily to provide supplemental heat for a swine farrowing house, grain drying, and peanut drying. This report gives information on the construction and operation of the portable solar collector.

The development and testing of the portable solar collector for crop drying and other applications was supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with William P. Edwards, the farm cooperator.

THE FARM

The Edwards farm is located approximately 8 miles north of Windsor on Isle of Wight County Road No. 647 near Central Hill Community. Crops grown on the farm, acres, estimated annual production, drying periods, and energy required to dry these crops are shown in Table 1. Grain and peanuts are dried in two 18' diameter and one 21' diameter grain bins equipped with forced air drying units and in a 9 trailer drying shed.

The cooperator is also engaged in swine production in a 24 stall farrowing house along with finishing facilities. The 24' x 100' farrowing house is a concrete block structure equipped with a sidewall mounted, thermostatically controlled, 150,000 BTU/hr. supplemental LP gas heater. The farrowing house requires an estimated 103.7 million BTU's of heat or the equivalent of 1,150 gallons of LP gas annually. Add to this the estimated 8,000 gallons of LP gas required for crop drying and the total annual usage on the farm comes to 9,150 gallons.

Table 1. Crops Produced and Drying Energy Requirements.

Crop	Acres	Yield
Peanuts	175	586,205 lbs.
Corn	260	23,400 bu.
Soybeans	225	5,625 bu.
Wheat	120	4,800 bu.
Barley	120	6,300 bu.
Oats	10	600 bu.
Milo	20	1,400 bu.

Crop	Drying Periods	Energy Required Million BTU's
Peanuts	late Sept.-Oct.	439.7
Corn	late Aug.-Sept.	210.6
Soybeans	Nov.	23.6
Wheat	June-July	16.2
Barley	June	22.7
Oats	June	1.3
Milo	Nov.	9.0

OBJECTIVES

- Provide a practical and economically feasible portable solar collector.

- Utilize this collector for multiple-use applications (i.e. grain bin, trailer shed, farrowing house).

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914 and September 30, 1977, in cooperation with the U S Department of Agriculture Mitchell R Geasler, Interim Dean, Extension Division, Cooperative Extension Service, Virginia Polytecnnic Institute and State University, Blacksburg, Virginia 24061 M C Harding Sr., Administrator 1890 Extension Program, Virginia State University Petersburg, Virginia 23803

- Provide suitable rock storage to supply significant energy for heating the farrowing house.

SYSTEM DESIGN

Since supplemental heat is required at three locations (grain bins, trailer shed, and farrowing house) separated by several hundred feet, a portable solar collector was proposed. Heat requirements for the farrowing house extend over a 4 to 5 month period including winter months. Hence, the collector was sized and sloped to be of maximum benefit for winter application. In addition, a rock storage was designed to store heat and to supply preheated air to the farrowing house heater.

A 36' x 16' suspended plate collector was constructed and placed on a 9'-10 1/2" x 38' mobile home chassis. The 576 sq. ft. collector was positioned at an angle 50° from the horizontal and oriented to face due south at each location. A concrete block structure containing 30 tons of 2 inch diameter railroad ballast serves as a heat storage to accumulate energy for heating the farrowing house.

The average radiation received at the total solar collection surface area in the months of June through March ranges from 920,000 to 706,000 BTU's/day. At 50 percent efficiency for this insulated portable suspended plate solar collector, 460,000 to 353,000 BTU's/day is available to preheat the drying and swine house air potentially replacing 5.1 to 3.9 gallons of LP gas daily. If 75 percent of the solar energy available is utilized, the fossil fuel normally required to dry crops on this farm can be reduced by 6.9 percent or 556 gallons of LP gas. With an estimated supplemental heat requirement of 1,500 BTU's/hour per stall, a total of 103.7 million BTU's are required for the months of December, January, February, and March. With a storage efficiency of 75 percent, the portable collector/rock storage system should reduce the fossil fuel normally required for heating the farrowing house by 35 percent or an annual savings of 403 gallons of LP gas. A total annual savings of 959 gallons of LP gas might be expected from the collector when used for drying crops and heating a farrowing house.

The solar collector consists of a cover plate of clear corrugated fiberglass backed by a black painted corrugated metal absorber, separated by a 3/4" dead air space. A 1 1/2" live air channel is located between the metal absorber and 1/2" plywood wall paneling. An interior cavity is formed beteen the sloping collector and the supporting plywood covered exterior walls and floor. This area is insulated by 4" of rigid insulation to form a second live air channel.

During peanut and grain drying, the air is drawn through both air channels. The drying fan pulls the air through a total of 9 ft^2 of collector channel area at a rate of 7,000 cfm (theoretically 780 fpm).

When utilized for heating the farrowing house, air returns to the far end of the collector through the interior cavity and reverses back through the 1 1/2" channel to the rock storage. The concrete block structure located adjacent to the farrowing house is insulated with 4" of molded polystyrene. Air is moved to and from the rock storage structure by two thermostatically controlled 1/2 HP fans which add to or remove heat from the rock. One of the fans draws air through the solar collector into the plenum beneath the rock at a rate of 2,500 cfm. This fan operates when the air in the collector absorber is sufficiently hotter than the rock storage. When supplemental heat for the farrowing house is required, the second fan draws ambient air through

the rock storage and delivers it to the entrance of the existing LP gas heater.

COST

The total cost, including labor, for the 576 sq. ft. portable solar collector and the 10' x 10' x 8' 30 ton rock storage was $5,983.39 or $10.39 per sq. ft., of collector surface.

PERFORMANCE

The portable solar collector was constructed in 1981 and used as a supplemental heat source for both grain and peanut drying. Some data was collected on its performance when drying grain in 1981 and again in 1982. Results from data collected for the period September 1-20, 1982 are reported here. About 6,000 bushels of corn were dried in bins from 18.5% to 11.1% moisture content. The fan operated 290 hours and used 2,200 kwh of electricity. The burner operated 145.8 hours and used 755 gallons of LP gas. The solar collector contributed the equivalent of 58 gallons of LP gas for a 7.1% energy savings as compared with an estimated savings in the design criteria of 6.9%. The energy required including solar was 2,496 BTU and 0.075 kw per lb. of water removed at an LP gas and electricity cost of 9.31 and 0.45 cents per bushel, respectively. The total cost, not including solar, was 9.76 cents per bushel or 1.32 cents per bushel per percentage point of moisture removed. The solar collector contributed an average of 4.8 gallons of LP gas equivalent per day.

ECONOMIC ANALYSIS

Based on the data collected when drying grain and estimates of savings when using the solar collector with other heating applications, the unit is cost effective with or without tax credits. The assumptions are: the collector has a 15 year life, the annual inflation rate will be 6%, and the interest on the investment is 12% annually. The present value of the 15 year investment is $9,085.11. The payback period for the project as constructed is 6.9 years with tax credits and 9.2 years without tax credits. If the portable solar collector had been constructed for crop drying only, and no heat storage provided for swine house heating, the payback period would have been 1 to 1 1/2 years less.

Table 2. Economic Analysis of Solar Project (as constructed).

Total Energy Used: 8,191 gals.
Total Energy Saved: 959 gals.

Percent Savings: 10.5

Cost of Collector: $5,983.39
Cost of LPG/gal.: $.80

Payback w/Tax Credits: 6.9 yrs.
Payback w/o Tax Credits: 9.2 yrs.

Yearly Taxes and Insurance: $119.67
Annual Maintenance Cost: $119.67
Inflation Rate: 6%

Present Value of Energy Savings
Based on 12% Interest

Year	LPG Price	Present Value
1	.80	$ 685.07
2	.88	672.77
3	.97	660.77
4	1.06	648.94
5	1.17	637.34
6	1.29	625.94
7	1.42	614.88
8	1.56	603.85
9	1.71	593.03
10	1.89	582.50
11	2.07	572.10
12	2.28	561.89
13	2.51	551.87
14	2.76	541.90
15	3.03	532.29

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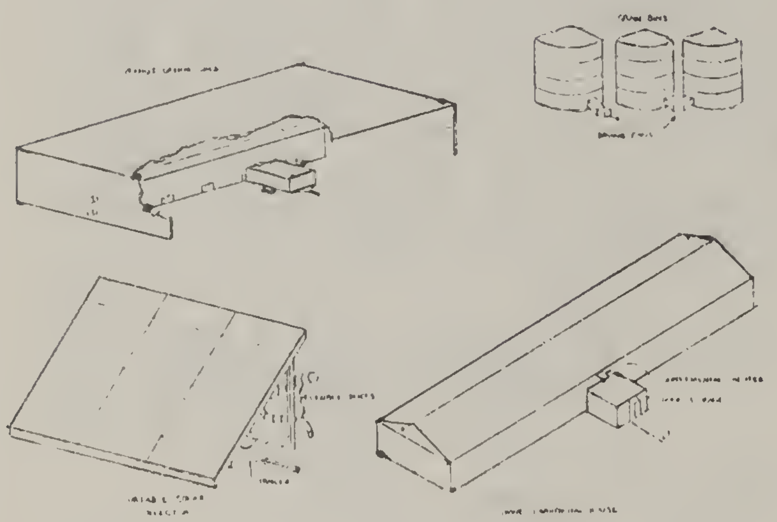
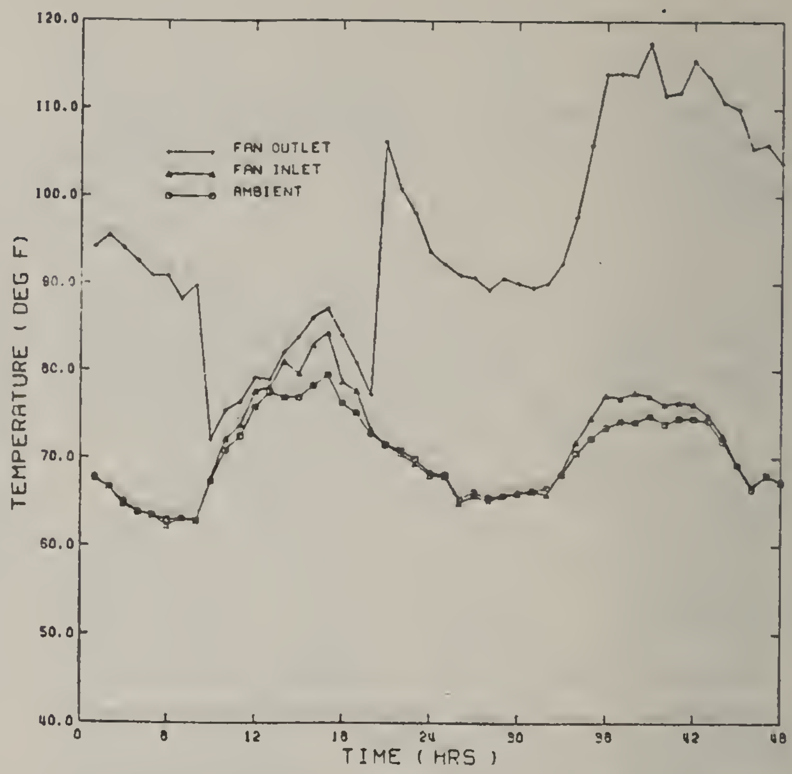
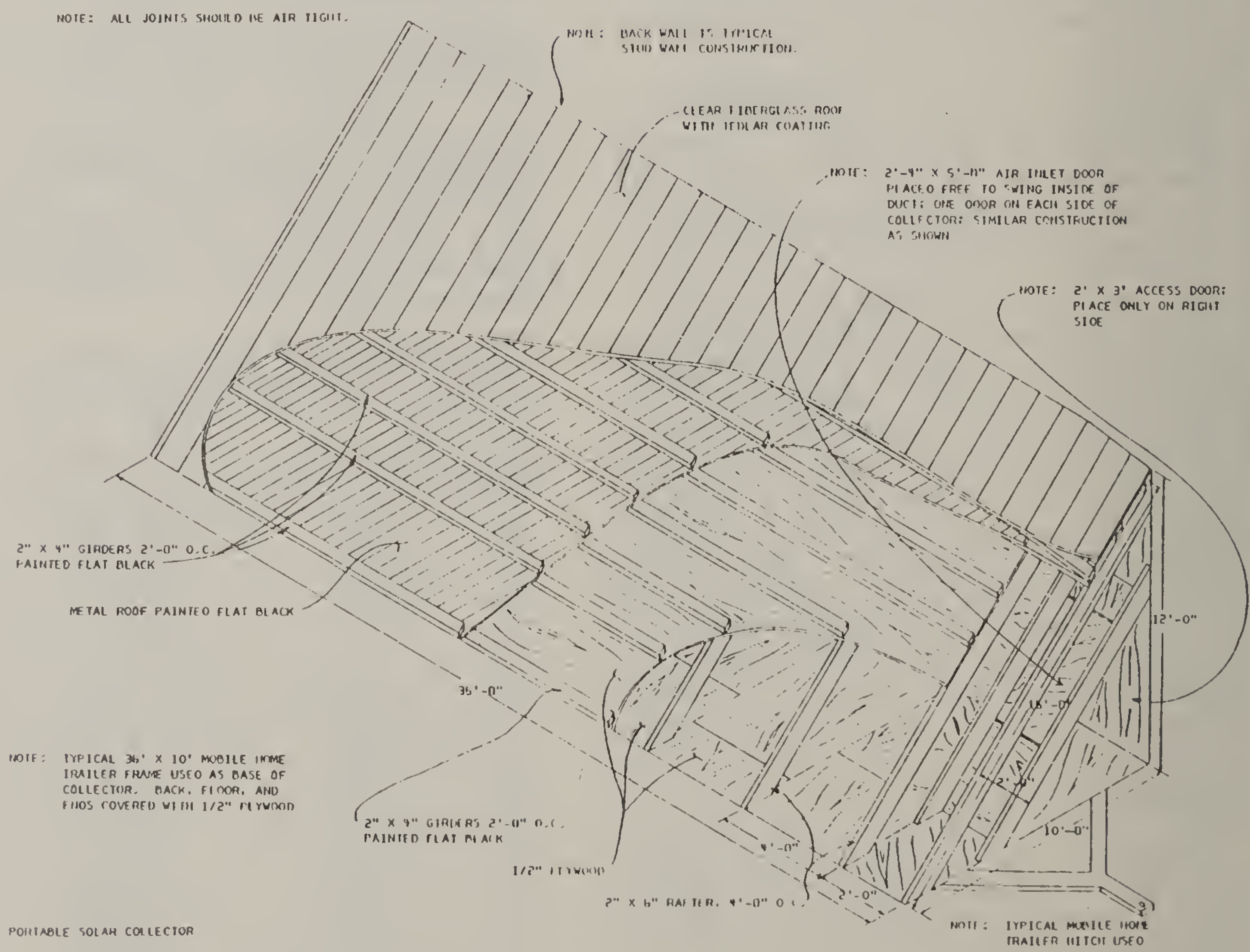
Net Present Value for 15 Years:
$9,085.11

System is cost effective w/tax credits.
System is cost effective w/o tax credits.





TYPICAL PERFORMANCE DATA FOR PORTABLE COLLECTOR LOCATED WILLIAM P EDWARDS FARM. DATA FOR SEPTEMBER 1982.



PORTABLE SOLAR COLLECTOR

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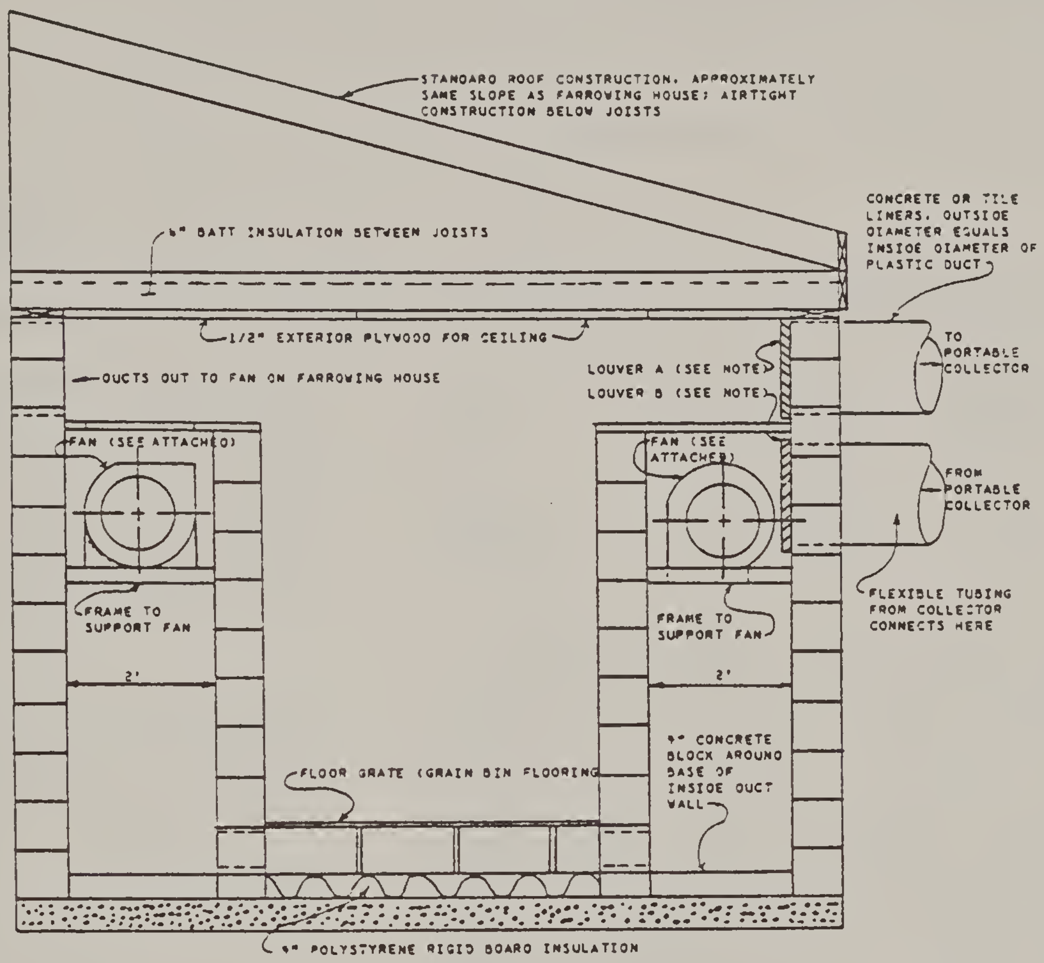
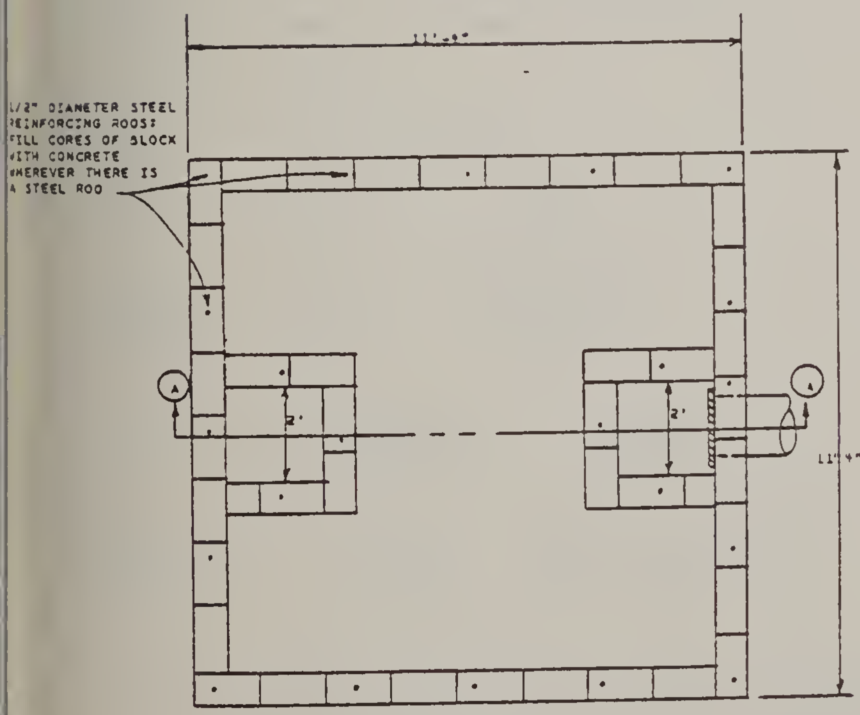


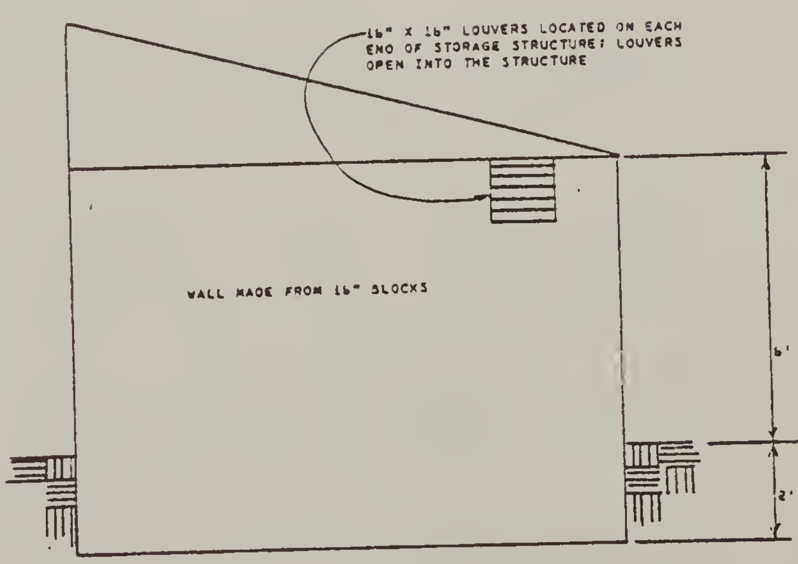
SECTION A

NOTES:

LOUVER A OPENS INTO DUCT WITH SUCTION 16" x 16".
LOUVER B OPENS AWAY FROM DUCT WITH PRESSURE 16" x 16".



CUT-AWAY TOP VIEW



OUTSIDE WALL VIEW

SOLAR CROP DRYING SERIES

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Agricultural Engineering

Eight Trailer Solar Assist Crop Dryer

A. J. Lambert and J. P. Harner, III

A demonstration solar assist crop dryer was constructed on a Southeast Virginia farm in 1981. It was designed to provide solar energy to assist with grain drying and peanut curing. This report gives information on the construction and operation of the demonstration project.

The development and testing of the solar assist dryer was supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U. S. Department of Energy along with Kermit Francis and Son, the farm cooperators.

THE FARM

The Francis farm is located on the north side of Southampton County Road #653 approximately 4.3 miles southwest of U.S. Highway 58 at Capron. Table 1 gives a summary of crops produced and energy required to dry these crops.

Table 1. Drying Energy.

Crop	Acres	Yield
Corn	350	35,000 bu.
Peanuts	225	675,000 lbs.
Soybean	50	1,250 bu.

Crop	Moisture Reduction	Drying Periods
Corn	25-20%	late Aug.-Sept.
Peanuts	30-10%	late Sept.-Oct.
Soybean	16-12%	Nov.

Crop	Drying Energy	Million BTU's
Corn	3,600 BTU/bu.	126.0
Peanuts	600 BTU/lb.	405.0
Soybean	5,600 BTU/bu.	7.0

Prior to 1981, crops were dried in five 18' diameter metal grain bins equipped with perforated floors and LP gas fired forced air drying units. Peanuts were dried in batches not exceeding five foot in depth. The eight trailer solar assisted drying structure was constructed to eliminate labor associated with filling and emptying batch lots of peanuts as practiced when drying in metal bins. The crops which might be dried in the facility require an estimated 538 million BTU's annually or the equivalent of 5,977 gallons of LP gas (90,000 BTU's/gal.). The supplemental heat requirements may be more or less depending on ambient air conditions during the fall drying season and the speed with which the crops are dried.

OBJECTIVES

- Provide a practical and economically feasible solar collector to preheat air for a trailer drying facility.
- Investigate the potential for increased savings through the addition of a solid metal vertical absorber with airflow on both sides.
- Examine the performance of the collector while utilizing various airflow patterns into the collection area.

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- Investigate the potential for more efficiency through partial recirculation of air.

SYSTEM DESIGN

The facility, designed primarily as a trailer drying unit for peanuts, makes use of a conventional truss roof shed, two crop drying fans equipped with LP gas burners, an air distribution duct, and 8 trailers with perforated metal floors. The 50'x 48' building incorporates a covered plate solar collector on the southern roof slope. A 9'-8" x 50' greenhouse structure, which interfaces the south wall, houses the crop drying units and serves as a collection area for the solar heated air.

The covered plate collector and the greenhouse area have a total of 2,418 ft^2 of solar collection surface. The roof collector contains 1,825 ft^2 at a 22.6^o slope (5/12 pitch), the vertically south wall adds 400 ft^2 and the end walls of the greenhouse area accounts for 193 ft^2.

The average radiation on the total solar collection surface area from September through November was projected at 3.58 to 2.71 million BTU's/day, respectively. With an estimated 40% efficiency for this collecting system, 1.43 to 1.08 million BTU's/day of potential savings were expected or 15.9 to 12.0 gallons of LP gas daily. With 75% of the available solar energy effectively utilized, fuel should be reduced by 16% or 956 gallons of LP gas annually.

The air inlet is located under the ridge of the drying shed to allow partial recirculation of the drying air. Warmer than ambient air should naturally rise to the ridge inlet where it is pulled into the collector. The air passes through the roof collector to the air collection area. A portion of the air entering the greenhouse collection area is directed downward behind the vertical corrugated metal absorber before it mixes with the air in the collection area. Additional savings should result from increased efficiency by partial recirculation of drying air. Approximately 48,000 cfm (mfg. fan ratings) of air is moved through the collector.

Figures 2 and 3 give construction information for the system.

COST

The eight trailer shed cost $11,627.39 to construct not including two crop drying fan units and trailers. The portion of this cost, including labor, for the 2,418 sq. ft. of solar collector and related greenhouse air collection area was $3,436.01 or $1.42/sq. ft. of collector surface.

PERFORMANCE

The solar assist drying facility was first operated in September, 1981, for drying corn and later for curing peanuts. During a 16 day period from October 21 to November 5 the drying system was monitored and actually operated 4.3 days. The average fuel savings were 2.4 gallons per hour or 32 percent during the 4.3 days. Total savings for the test period were 244 gallons or 22 million BTU's. It can be observed from Figure 1 that fan inlet temperature was always greater than ambient air temperature. This difference can be attributed to heat added by solar and partial reuse of drying air. The difference in the temperature between the fan inlet and outlet is the heat added by the fan motor and LP gas. The velocity of the air moving through the covered plate collector and the wall collector was 600 fpm. During the fall of 1981, a few trailer loads of corn and a total of 636,299 lbs. of peanuts were dried, an exceptionally large amount for an 8 trailer drying system. Fuel use was

4,182 gal. of LP gas and electricity amounted to 8,470 KWHr. Peanut grade factors as indicators of quality were very good. If sound split kernels are over two percent, the drying rate is too fast. Split kernels were 1.43% as compared with a state average of 1.54%.

The facility was used to dry 19,100 bu. of corn and 585,320 lbs. of peanuts in 1982. Fuel heat from 4,580 gal. of LP gas was used. The data obtained by instrumentation corresponded very closely to that provided by the cooperator. The calculated total fuel energy required to dry these crops was 6,478 gal. of LP gas. Hence, 1,898 gal. of LP gas was saved by the integrated solar system or 29.3% of the total.

ECONOMIC ANALYSIS

Based on the data collected when drying grain and peanuts and information supplied by the cooperator, the facility is cost effective with or without tax credits. Assumptions made were that the collector has a 15 year life, the annual inflation rate will be 6%, and the interest on the investment is 12% annually. The present value of the 15 year investment is $17,306.46. The payback period for the project as constructed is 1.9 years with tax credits and 2.5 years without tax credits. The large volume of grain and peanuts dried in this facility make it a very good investment.

Table 2. Economic Analysis of Solar Project.

Total Energy Used: 4,580 gals.
Total Energy Saved: 1,898 gals.
Percent Savings: 29.29

Cost of Collector: $3,436.01
Cost of LPG/Gal.: $.77

Payback w/Tax Credits: 1.85 yrs.
Payback w/o Tax Credits: 2.46 yrs.

Yearly Taxes and Insurance: $68.72
Annual Maintenance Cost: $68.72
Inflation Rate: 6%

Present Value of Energy Savings
Based on 12% Interest

Year	LPG Price	Present Value
1	$ .77	$ 1,304.93
2	.84	1,281.58
3	.93	1,258.72
4	1.02	1,236.17
5	1.12	1,214.07
6	1.24	1,192.38
7	1.36	1,171.29
8	1.50	1,150.29
9	1.65	1,129.67
10	1.81	1,109.62
11	1.99	1,089.81
12	2.19	1,070.36
13	2.41	1,051.26
14	2.65	1,032.27
15	2.92	1,013.96

Net Present Value for 15 Yrs.: $17,306.46

System is cost effective w/tax credits.
System is cost effective w/o tax credits.

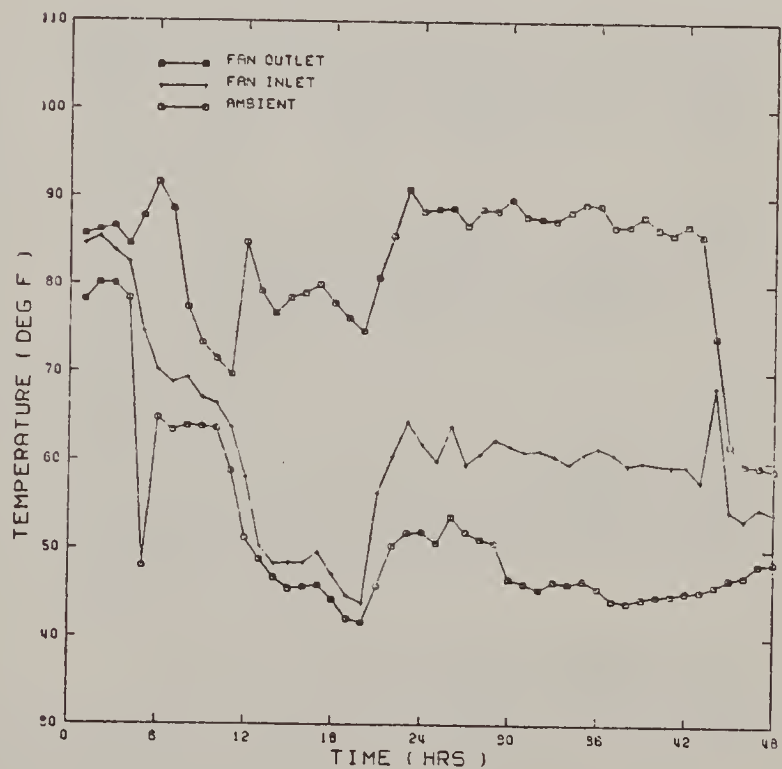

Figure 1. Typical performance data of eight trailer solar system (Kermit Francis farm).

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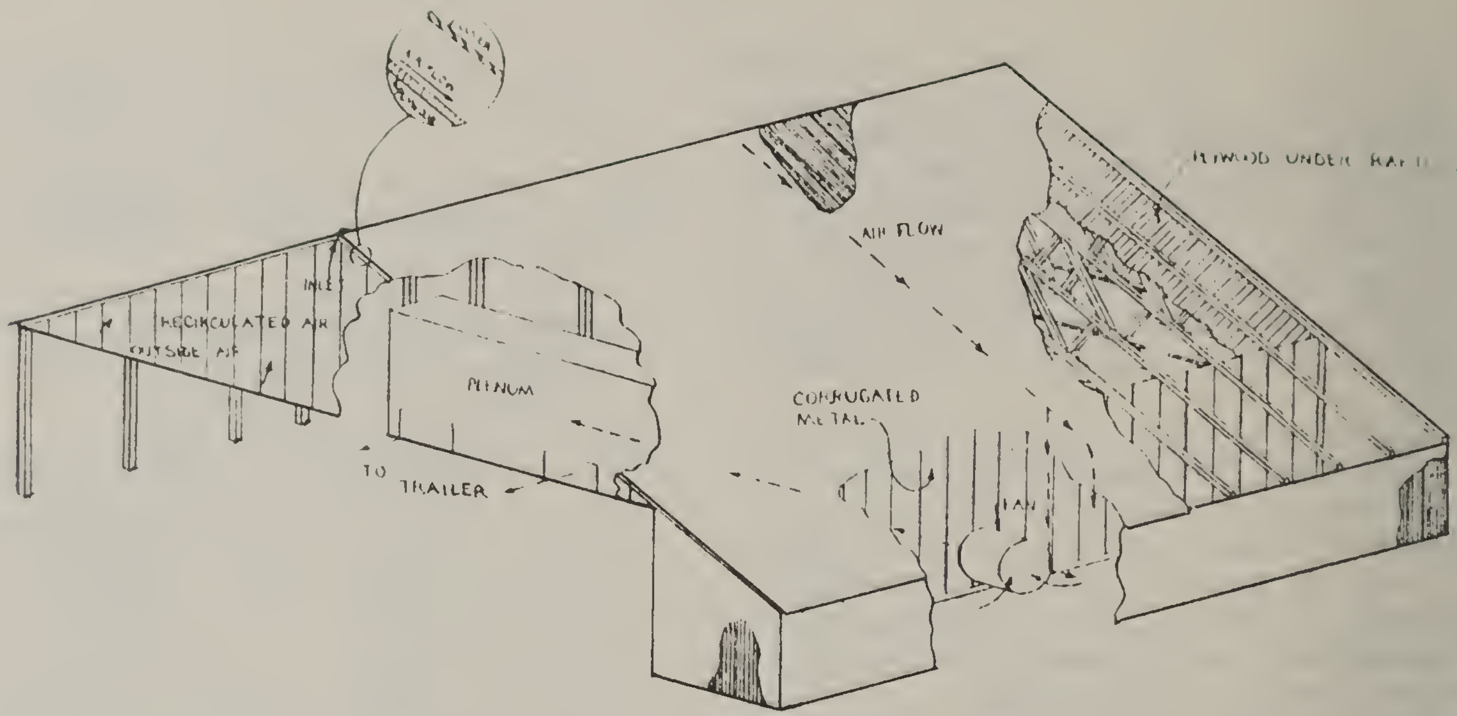

Figure 4. Airflow Pattern.

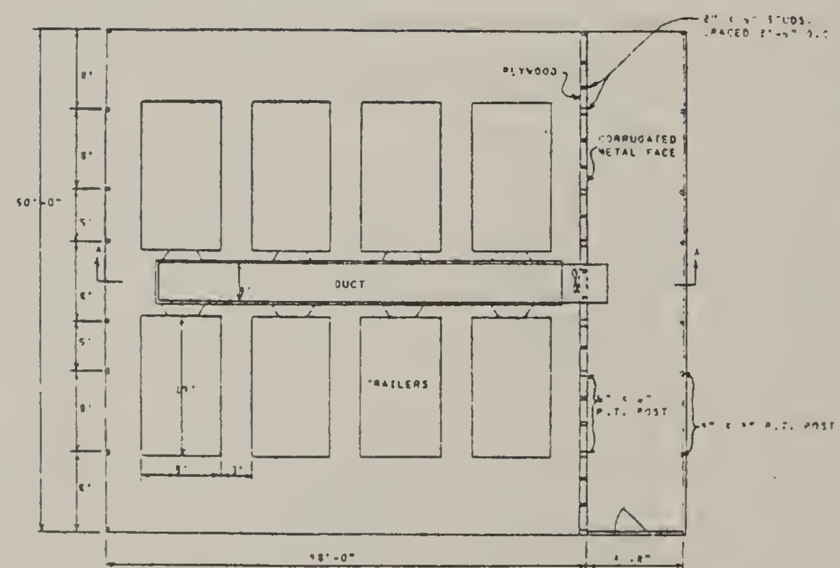

Figure 2. Plan.

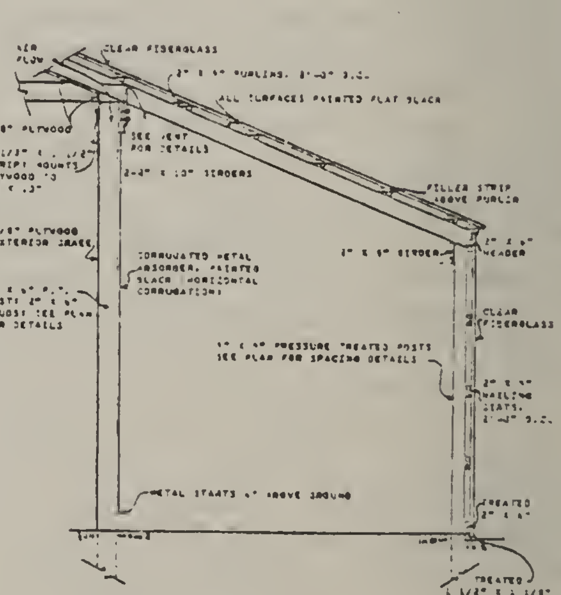

Figure 3. Section.

SOLAR CROP DRYING SERIES

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Agricultural Engineering

Add-On Solar Collector for Grain Drying and Shop Heating

A. J. Lambert and J. P. Harner, III

An existing 62' x 108' storage and equipment building was retrofitted to include a solar collector for demonstration on a northern Virginia farm. The collector was added to provide solar energy to assist with grain drying and shop heating. This report gives information on the construction and operation of the collector on the Joseph Hottel farm.

The development and testing of the solar assist heating unit was supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with the farm cooperator.

THE FARM

The Hottel farm is located 7.5 miles south of Purcellville on Loudoun county road 731. Table 1 gives a summary of crops produced and energy required for these crops.

Table 1. Energy Required.

Crop	Acres	Yield
Wheat	600	34,800 bu.
Corn	3,000	300,000 bu.
Soybeans	800	28,000 bu.

Crop	Drying Period	Energy Required Million BTU's
Wheat	June	20.9
Corn	Sept.-Oct.	4,783.9
Soybeans	mid Oct.-mid Nov.	307.4

These crops are dried with a combination of equipment including a 500 bu. per hr. continuous flow dryer, a 500 bu. per hr. recirculating batch dryer, and by an in-bin 14 HP 28" fan attached to a 25' diameter, 6,000 bu. bin. Approximately 200,000 bu. can be stored in 8 bins at this location. A bank barn used for equipment storage is adjacent to the grain storage facility on the west side and a 60' x 80' shop is located on the southeast corner. An estimated total of 5,204 million BTU's or the equivalent of 57,820 gallons of LP gas (90,000 BTU's/gal.) is used annually to dry crops.

OBJECTIVES

- Provide a practical and economically feasible solar collector to preheat air for in-bin grain drying and shop heating.
- Determine the operational value of a low cost attic collector constructed from an existing storage building for in-bin grain drying and shop heating.
- Investigate the potential for using solar heated air during the combination grain drying process.

SYSTEM DESIGN

The metal roof of the 62' x 108' bank barn was available to serve as a bare plate collector. An attic below the roof was available as an air collection area.

Utilizing the attic (ridge line running N 8° E) 7,452 ft^2 of metal

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roof serves as the absorber. The exterior surface of the 5v metal roof was painted flat black. The attic serves as an air channel between the metal roof and an existing plywood floor laid on top of the ceiling joist. Additionally, 490 ft^2 of corrugated fiberglass was placed on the S 8° W end of the attic as a vertical covered plate collector. Air is drawn through the attic (parallel to the ridge line) and ducted to the entrance of the bin dryer or to the shop fan.

A 19 ft^2 inlet consisting of cracks between vertical boards is located at the north end of the attic for the entrance of ambient air. The air is drawn the length of the attic (108') to a 4' x 4' duct located on the south gable end attic floor of the barn. Utilizing a two way damper, this preheated air is either ducted to the entrance of the fan at the 6,000 bu. bin or to the 60' x 80' shop. This system contains no thermal insulation or arrangement for heat storage other than that inherent in the construction materials.

The average radiation received at the total solar collection surfaces of 7,942 sq. ft. in the months of September through the following January ranges from 9.58 to 3.70 million BTU/day, respectively. The solar assist grain dryer and shop heater is located at 39° 5' north latitude and 46.9% of the collector faces N 82° W, 46.9% faces S 82° E, and 6.2% faces S 8° W. A 25% efficiency was anticipated for this combination bare plate and covered plate collector making available 2.39 to 0.92 million BTU's/day for preheating air, potentially replacing 26.6 to 10.3 gallons of LP gas daily. With a 90% utilization rate for grain drying and 50% for shop heating, solar energy can substitute for 1,553 and 1,031 gallons of LP gas, respectively. Because of the large volume of grain dried, solar energy was expected to substitute for only 2.7% of the fossil fuel used.

COST

The total cost, including labor, for construction of the collector for grain drying was $2,615.90. This does not include the cost of a duct to the repair shop. It includes paint for the barn roof which was beginning to rust. The cost of the collector for grain drying is 33 cents per sq. ft. of surface.

PERFORMANCE

The collector was first used in the fall of 1982 to assist with grain drying. Early in the corn harvesting season, the bin dryer attached to the solar collector was used as part of a combination drying system. Corn was dried to 17-18% moisture content by the continuous flow or recirculating batch dryer. The hot corn was then placed in the bin and dried to 13-15% moisture content without supplemental LP gas heat.

After the moisture content dropped to 20% or less in the field in mid-October, the corn was placed directly in the bin attached to the solar collector. Data were obtained on one batch covering a 16 day period beginning on October 21, 1982. An average of 9.5 gallons/day of LP gas were saved during this period which represented 4.8 cents per bushel. The average temperature rise above ambient generated by the solar collector from 9 a.m. to 5 p.m. on 3 clear sunny days during the period was 9°F.

It is estimated that five 5,000 bu. batches of grain can be dried in the 6,000 bu. bin during a season without any LP gas or saving 760 gal. of fuel. An estimated 903 gal. of LP gas or heat equivalent is required to dry 25,000 bu. from 18% moisture content to 13%. The equivalent energy required to power the fan is estimated

at 380 gal. of LP gas. Hence, 66% of total energy required is contributed by the solar system.

ECONOMIC ANALYSIS

Based on data collected when drying grain the system is cost effective with or without tax credits. Assumptions made are that the collector has a 15 year life, the annual inflation rate will be 6%, and the interest on the investment is 12% annually. The present value of the 15 year investment is $6,029.98. The payback period for the project as constructed is 4.3 years with tax credits and 5.7 years without tax credits. The project is economically attractive mainly for two reasons. The solar collector was relatively inexpensive to construct and the term of use is fairly long because of the large volume of grain produced.

Table 2. Economic Analysis of Solar Project.

Total Energy Used: 380 gals.
Total Energy Saved: 760 gals.
Percent Savings: 66.6%

Cost of Collector: $2,615.90
Cost of LPG/Gal.: $.67

Payback w/Tax Credits: 4.3 yrs.
Payback w/o Tax Credits: 5.7 yrs.

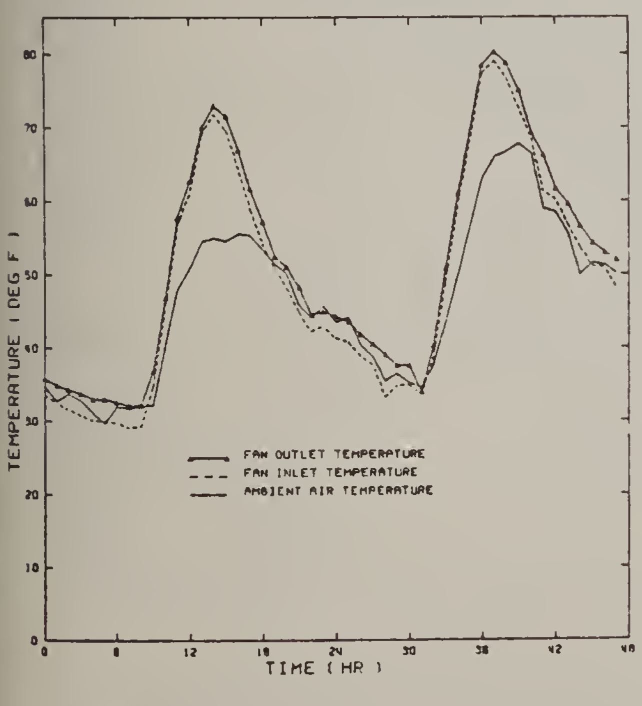
Yearly Taxes and Insurance: $52.31
Annual Maintenance Cost: $52.31
Inflation Rate: 6%

Present Value of Energy Savings
Based on 12% Interest

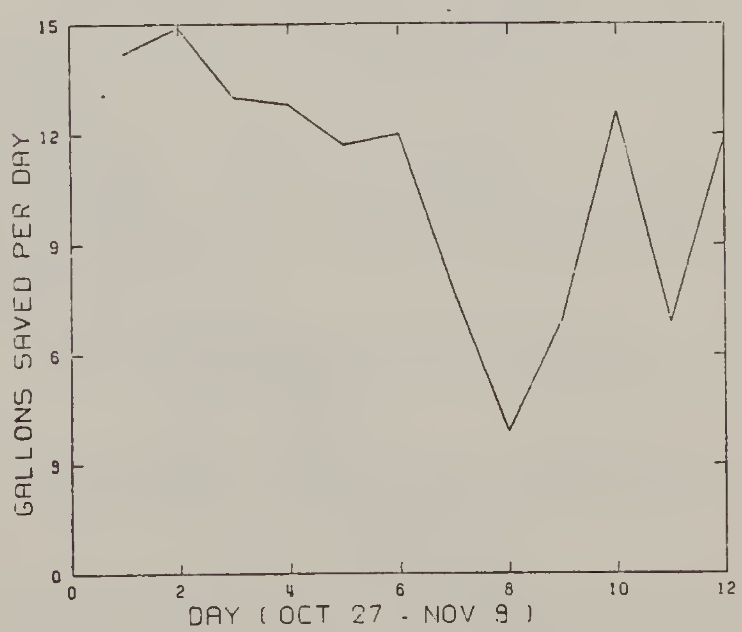
Year	LPG Price	Present Value
1	$ .67	$ 454.66
2	.73	446.52
3	.81	438.56
4	.89	430.70
5	.98	423.00
6	1.07	415.44
7	1.18	408.10
8	1.30	400.78
9	1.43	393.60
10	1.57	386.61
11	1.73	379.71
12	1.91	372.93
13	2.10	366.28
14	2.31	359.66
15	2.54	353.28

Net Present Value for 15 Years: $6,029.89

System is cost effective w/tax credits.
System is cost effective w/o tax credits.



PERFORMANPCE DATA FOR HOTTELS SOLAR COLLECTOR



LP gas saved for 12 day period.

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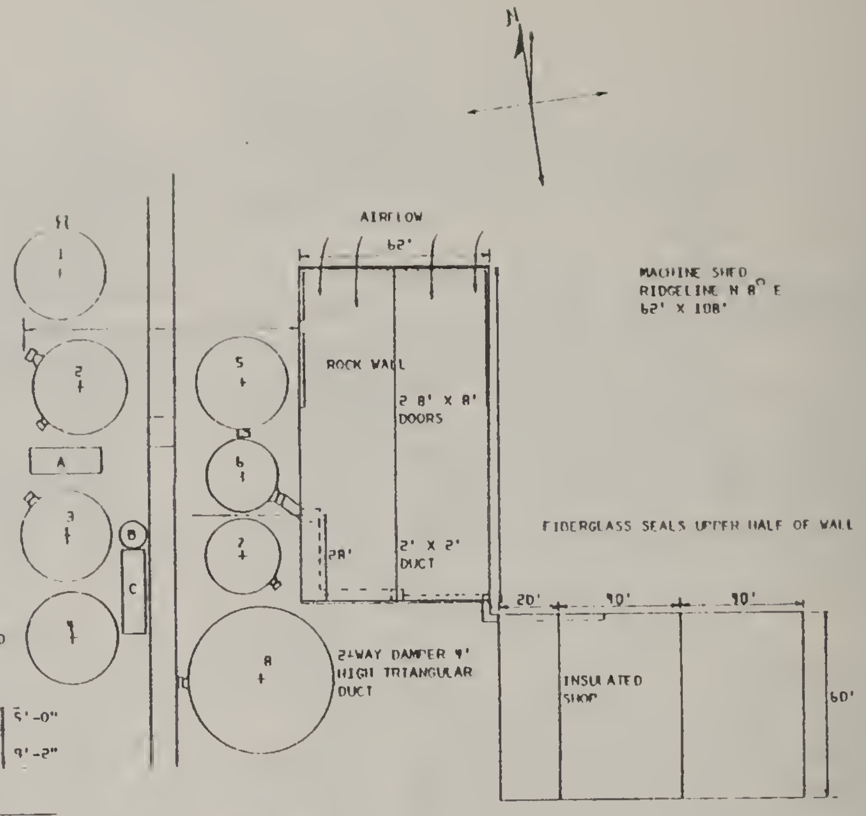
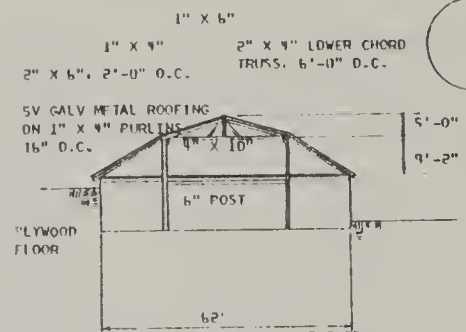
KEY:

BINS
1, 2, 3, 4, 5, = 30" DIA
6 = 25' DIA, 16' H, 6,000 BU, 28" DIA FAN WITH 14 HP MOTOR, 12,000 CFM AT 4" S.P.
7 = 25' DIA
8 = 48' DIA, AERATION, 9 RINGS

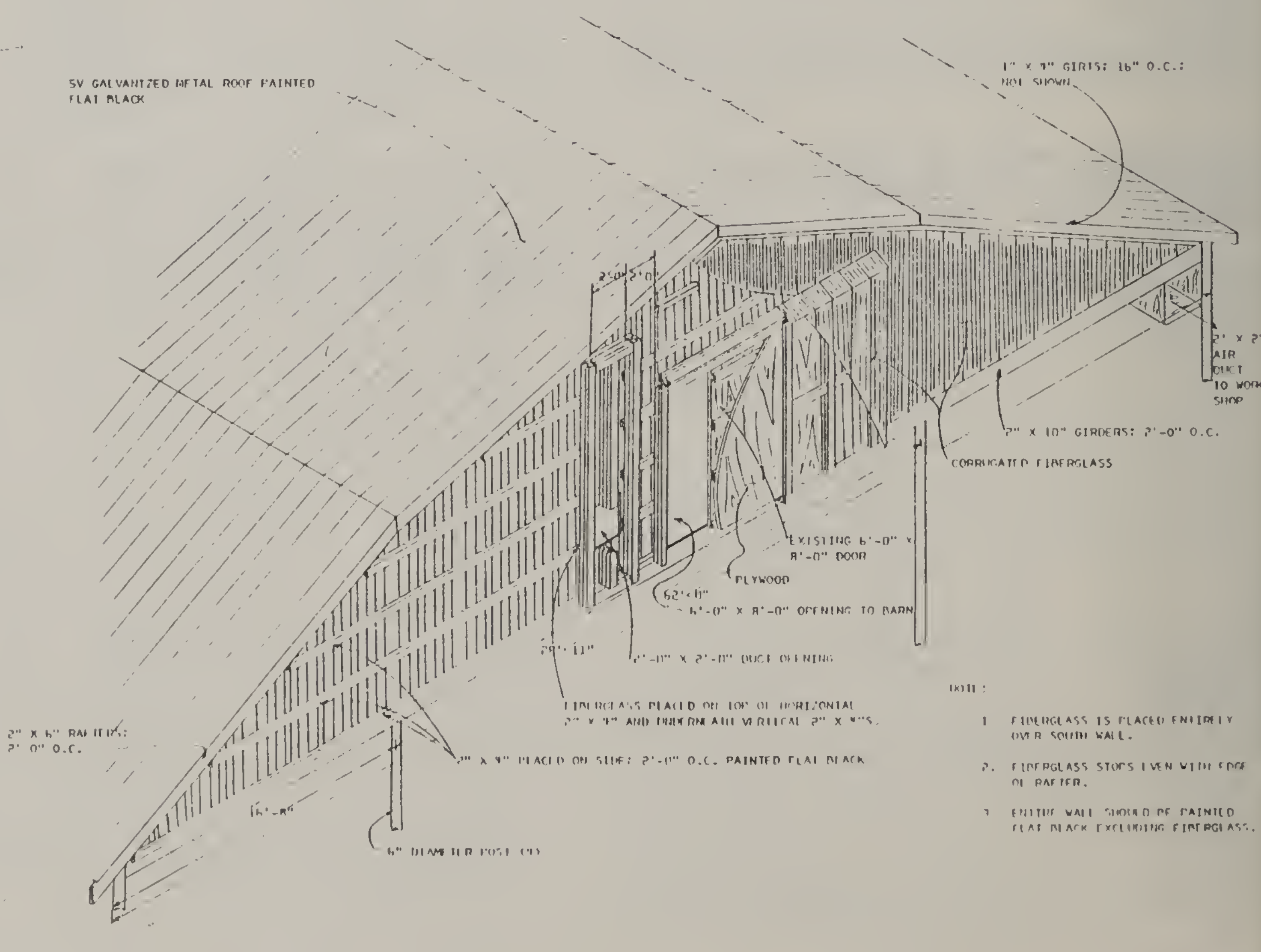
DRYERS
A = 8' X 24' DRI-ALL CONT. FLOW, 500 BU/HR
B = WET GRAIN HOLDING BIN
C = 8' X 22' BATCH DRYER, 500 BU, @25 TO 15%



FARM LAYOUT



ATTIC SECTION FOR MACHINE SHED



NOTE:

1. FIBERGLASS IS PLACED ENTIRELY OVER SOUTH WALL.
2. FIBERGLASS STOPS EVEN WITH EDGE OF RAFTER.
3. ENTIRE WALL SHOULD BE PAINTED FLAT BLACK EXCLUDING FIBERGLASS.

Agricultural Engineering

SOLAR CROP DRYING SERIES

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Solar Crop Drying in Six Trailer Shed (Pulley Farm)

A. J. Lambert and J. P. Harner, III

A new six trailer solar crop dryer was completed on a southeast Virginia farm in 1981 to dry grain and peanuts. This report gives information on the construction and operation of the demonstration unit on the Robert Pulley and Son farm.

The development and testing of the solar assist dryer was supported by the Extension Division of Virginia Polytechnic Instititute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with the farm cooperators.

THE FARM

The Pulley farm is located nearly 2 miles south of Ivor on county road 600 south of its intersection with county road 616 in Southampton County. Table 1 gives a summary of crops produced and energy required to dry these crops.

Table 1. Drying energy.

Crops	Acres	Yield
Peanuts	62	217,000 lbs.
Soybeans	65	2,275 bu.
Corn	100	10,000 bu.

Crops	Drying Period	Energy Required Million BTU's
Peanuts	late Sept.-Oct.	130.2
Soybeans	Nov.	12.7
Corn	late Aug.-Sept.	107.9

Interest in the construction of a new solar crop drying facility was primarily centered on a better arrangement for drying peanuts. A 20 year old custom built dryer facility with conveyor handling was formerly used for peanut drying and will continue to be used for seed drying and storage. The cooperator expects to continue to use a metal grain bin equipped with drying and stirring equipment for corn drying. The peanut and soybean crops which are dried in the solar assist trailer drying system require an estimated 142.9 million BTU's annually or the equivalent of 1,588 gallons of LP gas (90,000 BTU's/gal.).

OBJECTIVES

- Provide a practical and economically feasible solar collector to preheat air for a trailer drying facility.

- Investigate the potential for increased savings through the addition of a solid metal absorber both under rafters and on side wall with airflow on both sides.

- Examine the performance of the collector while utilizing various airflow patterns into the collection area.

- Analyze the performance of a partial attic type covered plate collector.

- Investigate the potential for increased system efficiency through partial recirculation of air.

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, and September 30, 1977, in cooperation with the U. S. Department of Agriculture. Mitchell R. Geasler, Interim Dean, Extension Division, Cooperative Extension Service, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061; M. C. Harding, Sr., Administrator, 1890 Extension Program, Virginia State University, Petersburg, Virginia 23803

SYSTEM DESIGN

The six trailer pole type 36' x 48' drying shed with truss roof is typical construction used on farms in southeast Virginia in recent years. A 8'-2" x 48' solar greenhouse was added to the southwest side of the shed to form a solar heated air collection area. The solar surfaces of 1,933 sq. ft. are made up by utilizing the southwest roof of the shed plus the roof and 8'-7" vertical wall of the S 14° W facing collection area. The roof collector which is at a slope of 22.6° (5/12 pitch) accounts for 1,352 sq. ft. of the total.

A clear corrugated fiberglass cover substituted for the metal roof normally used on the shed type structure. The covered plate treated for ultraviolet light (minimum 5 oz. per ft^2) along with a flat black corrugated metal and exterior grade plywood absorber functions as the main components of the collector on the south roof of the drying shed. The plywood is arranged on cords below the rafters to form an attic type space under the cover plate. The corrugated metal absorber is attached to the underside of the rafters so that air may flow on both sides of the metal. The cover plate on the outer walls and roof of the attached structure is constructed using the same type fiberglass. The absorber in the interior sidewall of this structures is painted black, horizontally corrugated, metal sheathing extending down to 6 inches from the groundline and approximately 8 inches in front of a 3/8 inch exterior grade plywood wall. Used metal roofing material served as the absorber. The plywood wall is interfaced with the drying shed and encloses the integrated collector shed.

The inlet for the collector is located under the ridge of the drying shed. The inlet air is taken from the inside of the drying shed allowing partial air recirculation. This air receives heat from the absorber and other components as it is brought into the roof attic. The fan in the drying unit pulls the air through the collector. Upon reaching the integrated shed, the airflow is channeled both directly into the integrated collection area and down between the metal absorber and the plywood wall before it reaches the fan. A damper at the entrance to the collection area can be adjusted to vary the airflow to each area. The preheated air is forced through the drying unit, into the plenum, and through the drying trailers. This solar collector is designed to function whenever the fan is in operation. This system contains no thermal insulation or arrangement for heat storage other than that inherent in the construction materials. Adjustable vents were installed in the ends of the integrated shed and gable ends to allow for natural air circulation when the dryer is not operating.

The average radiation received at the total solar collection surfaces of 1,933 sq. ft. in the months of September through November ranges from 2.81 to 2.14 million BTU's/day, respectively. The solar assist crop dryer is located at 36° 45' north latitude and 91% of the collector faces S 14° W. A 40% efficiency was anticipated for this combination covered plate-integrated shed solar collector making available 1.12 to 0.86 million BTU's/day for preheating the drying air, potentially replacing 12.5 to 9.5 gallons of LP gas daily. With a 50% utilization rate solar energy was expected to reduce fossil fuel required to dry peanut and soybean crops by 21%. This represents an annual savings of 334 gallons of LP gas.

COST

The total cost, including labor, for all construction related to the solar aspects of the six trailer crop drying shed was $2,714.26 or $1.41 per sq. ft. of collector surface. The cost of the solar addition would not be saved if only the shed were built since the fiberglass roof substituted for a metal roof used in typical non-solar construction.

PERFORMANCE

During the fall of 1981, 187,200 lbs. of peanuts were dried in the facility and 570 gallons of LP gas were used. Energy consumption amounted to 1,940 kwh. Energy cost to dry in the facility was 31 cents per cwt (75 cents/gal. LPG and 7.8 cents/kwh). The accompanying graph shows up to 11°F temperature rise over that of ambient air at the fan inlet for the sunny day period which is the equivalent of about 2.5 gallons of LP gas per hr.

ECONOMIC EVALUATION

Based on information collected in 1982 and other assumptions when drying peanuts, the solar collector is cost effective with or without tax credits. The assumptions are: the collector has a 15 year life, the annual inflation rate is 6%, and the interest on investment is 12% annually. The present value of the 15 year investment and limited use is $4,343.94. The payback period for the project as constructed is 6.5 years with tax credits and 8.7 years without tax credits. The payback period can be reduced by using the system for grain drying also.

Table 2. Economic Analysis of Solar Project.

Total Energy Used: 1,111.6 gals.
Total Energy Saved: 476.4 gals.
Percent Savings: 30

Cost of Collector: $2,714.26
Cost of LPG/Gal.: $.77

Payback w/Tax Credits: 6.5 yrs.
Payback w/o Tax Credits: 8.7 yrs.

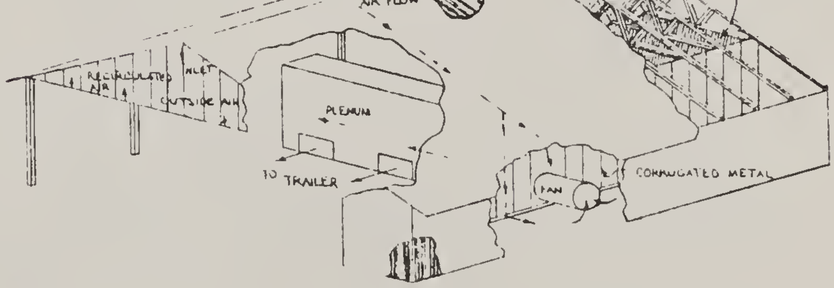
Yearly Taxes and Insurance: $54.28
Annual Maintenance Cost: $54.28
Inflation Rate: 6%

Present Value of Energy Savings
Based on 12% Interest

Year	LPG Price	Present Value
1	$ .77	$ 327.54
2	.84	321.67
3	.93	315.94
4	1.02	310.28
5	1.12	304.73
6	1.24	299.28
7	1.36	293.99
8	1.50	288.72
9	1.65	283.55
10	1.81	278.51
11	1.99	273.54
12	2.19	268.66
13	2.41	263.86
14	2.65	259.10
15	2.92	254.50

Net Present Value for 15 yrs.: $4,343.94

System is cost effective w/tax credits.
System is cost effective w/o tax credits.



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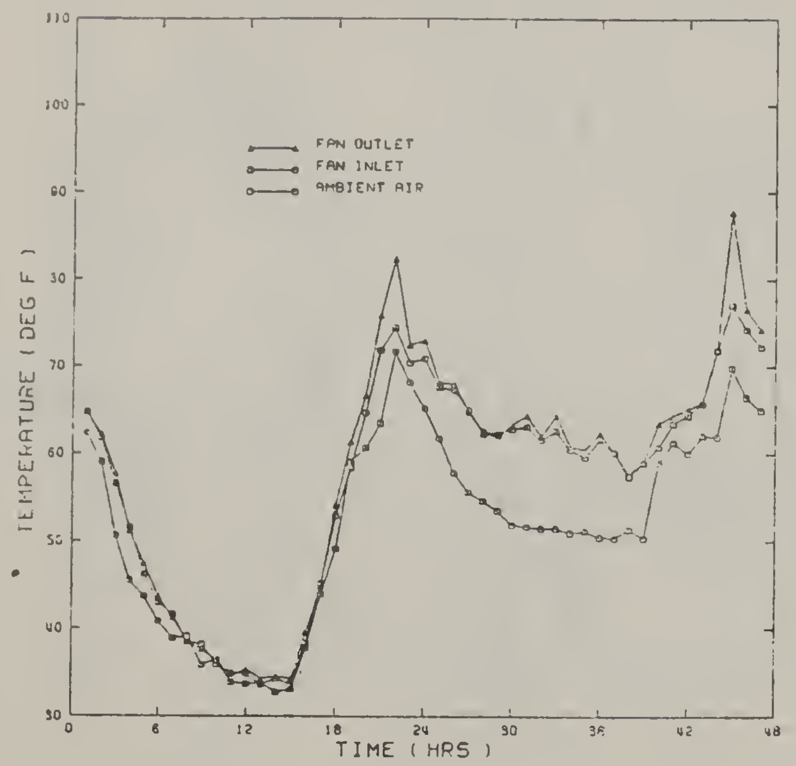
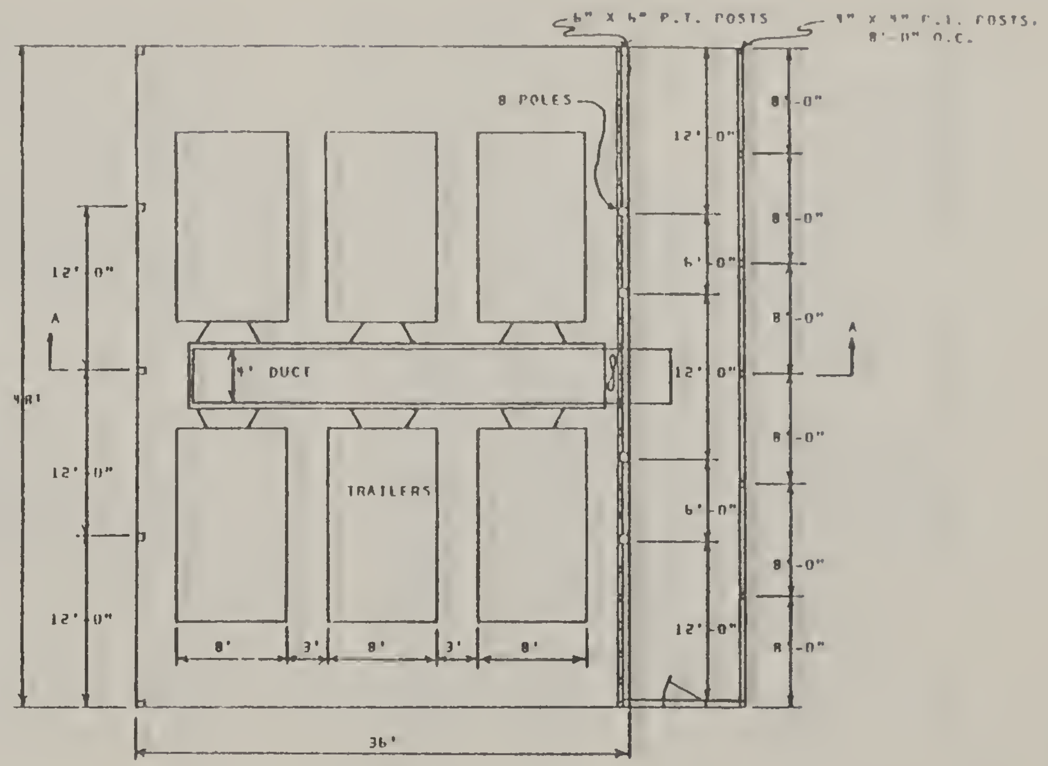
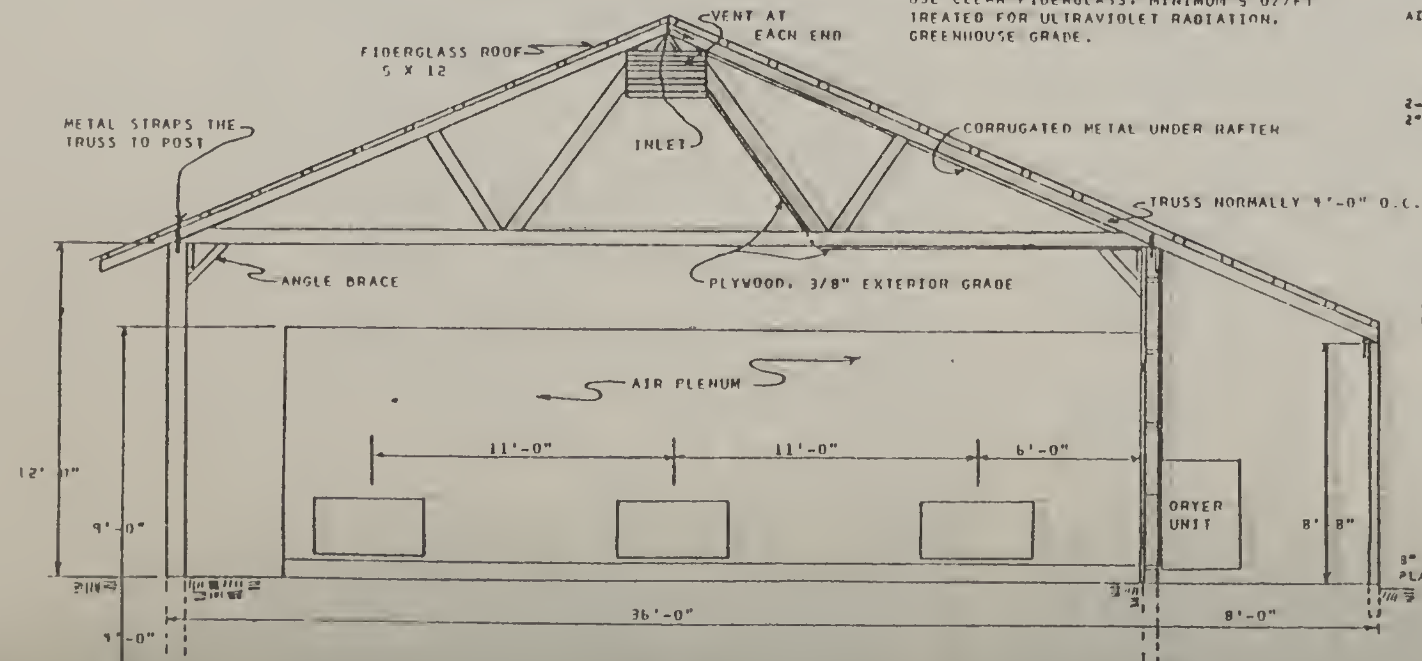


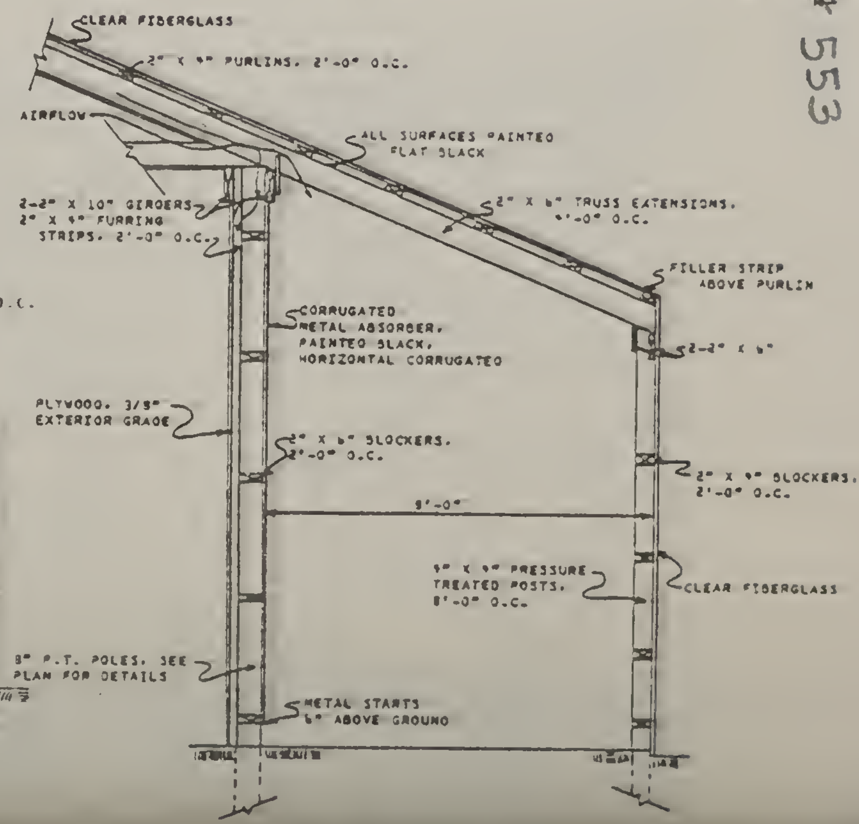


PLAN

NOTE:
USE CLEAR FIBERGLASS, MINIMUM 5 OZ/FT^2
TREATED FOR ULTRAVIOLET RADIATION,
GREENHOUSE GRADE.



SECTION A-A



SECTION USING STUD WALL CONSTRUCTION

Agricultural Engineering

Solar Crop Drying in Six Trailer Shed (Veliky Farm)

A. J. Lambert and J. P. Harner, III

An original design six trailer solar crop drying shed was constructed near the western edge of Virginia's peanut belt to dry peanuts and grain. This report gives information on the construction and operation of the demonstration unit on the Ben Veliky farm in Greenville County.

The development and testing of the solar assist dryer was supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with the farm cooperator.

THE FARM

The Veliky farm is located 8 miles north of Emporia on the left side of county road 619. Table 1 gives a summary of crops produced and energy required for drying on this farm.

Table 1. Drying Energy.

Crop	Acres	Yield
Peanuts	107	394,500 lbs.
Corn	60	3,960 bu.
Soybeans	15	420 bu.

Crop	Drying Period	Energy Required Million BTU's
Peanuts	late Sept.-Oct.	224.7
Corn	mid-Aug.-Sept.	42.8
Soybeans	Nov.	2.4

Prior to construction of the solar crop drying shed crops were dried in four 18' diameter metal bins. An estimated total of 269.9 million BTU's, equivalent to 3,000 gallons of LP gas (90,000 BTU/gal.) are needed to dry crops produced on this farm.

OBJECTIVES

- Provide a practical and economically feasible solar collector to preheat air for a trailer drying operation.
- Determine the value of utilizing an expanded metal lathing as an additional asborber.
- Investigate the potential for more efficiency through partial recirculation of air.

SYSTEM DESIGN

The six trailer pole-type 36' x 48' drying shed with truss roof is typical construction used on many farms in southeast Virginia in recent years. A 5'-6" x 48' solar greenhouse was added to the south side of the shed to form a solar heated air collection area. The solar surfaces of 1,827 sq. ft. are made up by utilizing the south facing roof of the shed plus the roof and 10' vertical wall of the greenhouse section. The roof collector which slopes at 22.6^{o} (5/12 pitch) accounts for 1,224 sq. ft. of the total.

A clear corrugated fiberglass cover substituted for a metal roof on the south side normally used in a non-solar structure. This cover plate, treated for ultraviolet light (minimum

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wt. 5 oz. per ft^2), along with a flat black 3/8" plywood absorber functions as the main components of the collector on the south roof of the drying shed. First grade clear fiberglass was used at this installation rather than heavier second grade material as used at some other installations. A black metal lathing (1" expanded to 5") was inserted between the fiberglass and the plywood to perform as an additional absorber to increase collector efficiency. The outer walls and roof of the attached structure uses the same fiberglass, backed with the black metal lathing. A flat black 3/8" exterior plywood wall, interfacing with the drying shed, encloses this collection area.

The inlet for the collector is located under the ridge of the drying shed. The inlet air is drawn from inside the drying shed, allowing partial air recirculation. The incoming air receives heat from the absorbers as it is drawn down the slope of the roof. The crop drying fan pulls the air through the collector into the greenhouse area and into the fan. The fan then forces the heated air into the plenum and through the drying trailers. This solar collector is designed to function whenever the fan is in operation. No thermal insulations or heat storage systems, other than those inherent in the construction materials, are used. A black painted concrete floor in the air collection greenhouse area serves as a heat storage mass.

The average radiation received at the total solar collection surface of 1,827 sq. ft. in the months of August to November ranges from 2.76 to 2.06 million BTU's/day, respectively. The crop dryer structure is located at 36° 35' N. latitude and 93% of the collector faces south. A 40% efficiency was anticipated for this combination covered plate-integrated shed solar collector making available 1.10 to 0.83 million BTU's/day for preheating the drying air, potentially replacing 12.2 to 9.1 gallons of LP gas daily. With a 50% utilization rate solar energy was expected to reduce fossil fuel required to dry crops on this farm by 19% which results in an annual savings of 570 gallons of LP gas.

COST

The total cost, including labor, for all construction related to the solar aspects of the six trailer crop drying shed was $3,309.20 or $1.81 per sq. ft. of collector surface.

PERFORMANCE

The facili¦y has been used mostly to dry peanuts. Much of the corn produced on this farm is still dried in metal bins. Two events have affected the use of the facility. One is reduced peanut yields in this area due to dry weather and the other is experimental manipulation of air recirculation in field tests to determine its value. The drying shed was totally enclosed to try to control the amount of air recirculation within the facility. After two seasons the idea of controlled air recirculation as managed by the farm cooperator has been abandoned. It required considerable operator attention due to changing weather and moisture levels in peanuts. Data collected shows that solar energy contributed 16% of the total energy required for drying for a typical month long period from mid-October to mid-November. Recirculation of air also contributes about this much savings; however, in a nearly enclosed environment there was considerable condensation on cool surfaces especially during still, cool nights.

Peanuts were the only crop dried in the trailer system in 1982. The cooperator reported that 211,920 lbs. were dried and 1,017 gal. of LP gas

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used. Based on other data obtained, at least 490 gallons of LP gas were saved which resulted in a 32.5% savings.

ECONOMIC ANALYSIS

Based on the data collected and other assumptions when drying peanuts, the unit is cost effective with or without tax credits. The assumptions are: the collector has a 15 year life, the annual inflation rate will be 6%, and the interest on investment is 12% annually. The present value of the 15 year investment is $4,642.02. The payback period for the project as constructed and used is 7.6 years with tax credits and 10.2 years without tax credits. Greater use of this trailer drying system would rapidly reduce the payback period.

Table 2. Economic Analysis of Solar Project.

Total Energy Used: 1,017 gals.
Total Energy Saved: 490 gals.
Percent Savings: 32.5%

Cost of Collector: $3,309.20
Cost of LPG/Gal.: $.80

Payback w/Tax Credits: 7.6 yrs.
Payback w/o Tax Credits: 10.2 yrs.

Yearly Taxes and Insurance: $66.18
Annual Maintenance Cost: $66.18
Inflation Rate: 6%

Present Value of Energy Savings
Based on 12% Interest

Year	LPG Price	Present Value
1	$ .80	$ 350.01
2	.88	343.75
3	.96	337.62
4	1.06	331.57
5	1.17	325.64
6	1.28	319.82
7	1.41	31417
8	1.55	308.53
9	1.71	303.00
10	1.88	297.62
11	2.07	292.31
12	2.28	287.09
13	2.51	281.97
14	2.76	276.88
15	3.03	271.97

Net Present Value for 15 Yrs.: $4,642.02

System is cost effective w/tax credits.
System is cost effective w/o tax credits.

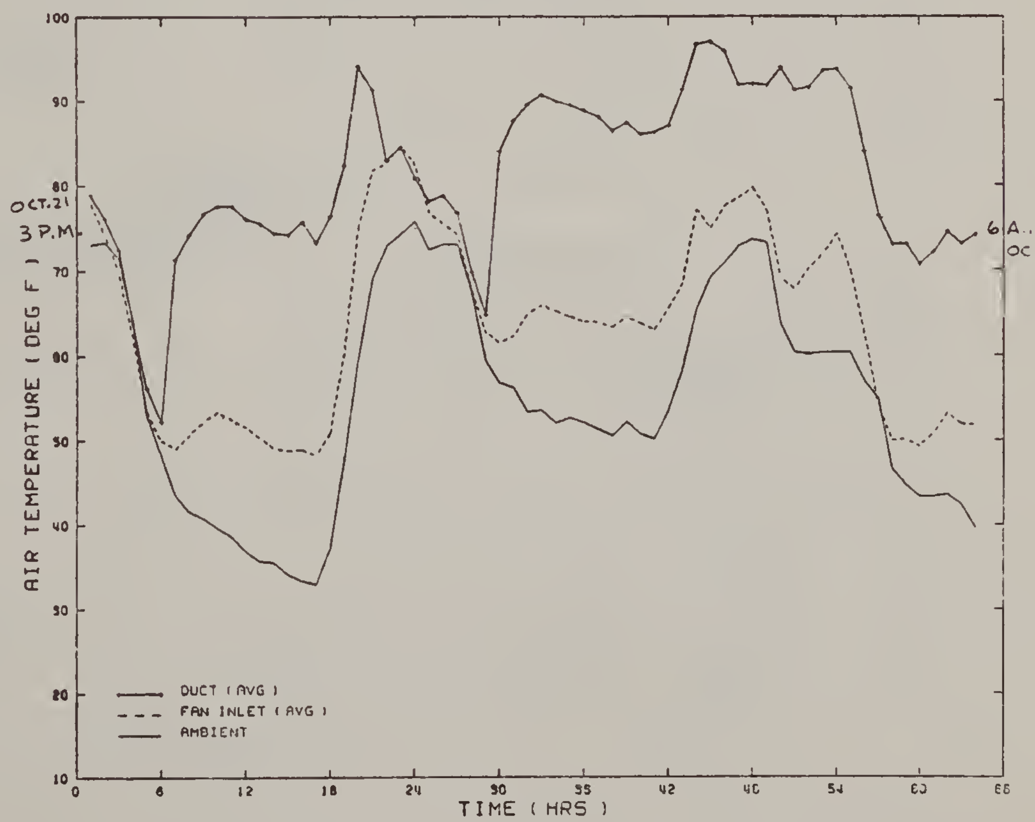

Figure 1. Performance curves (1981).

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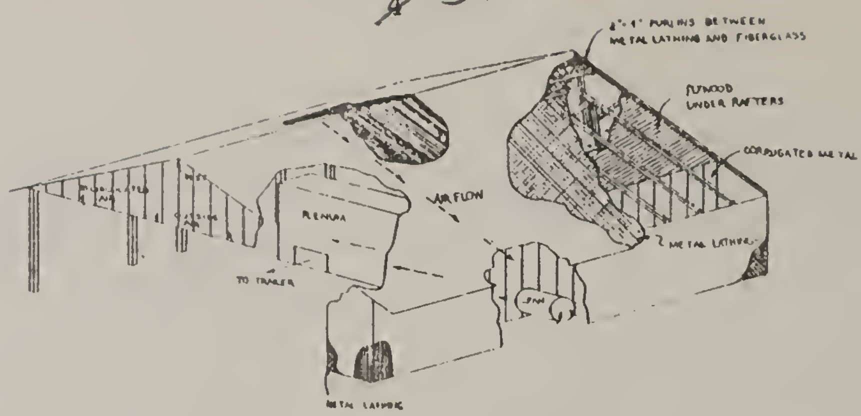
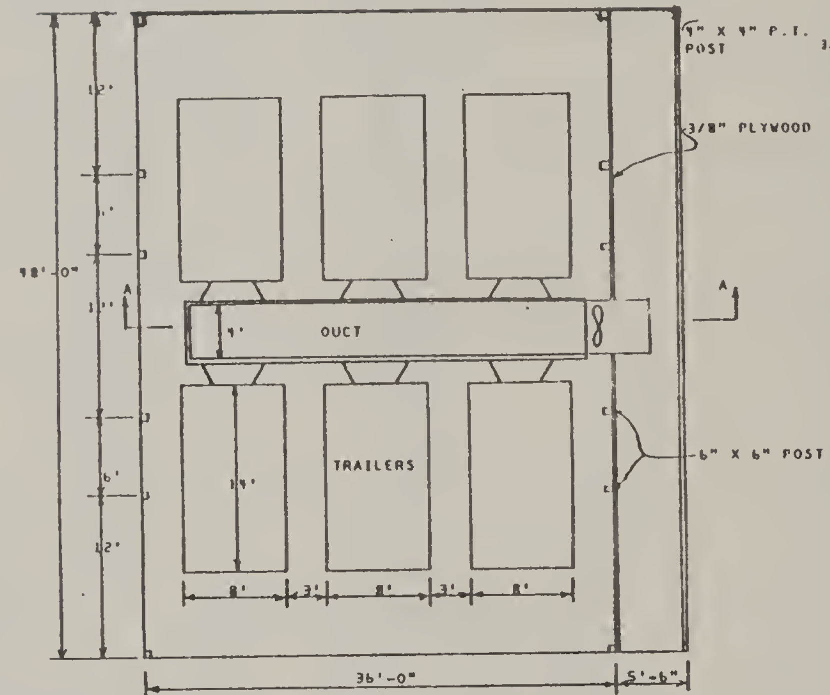
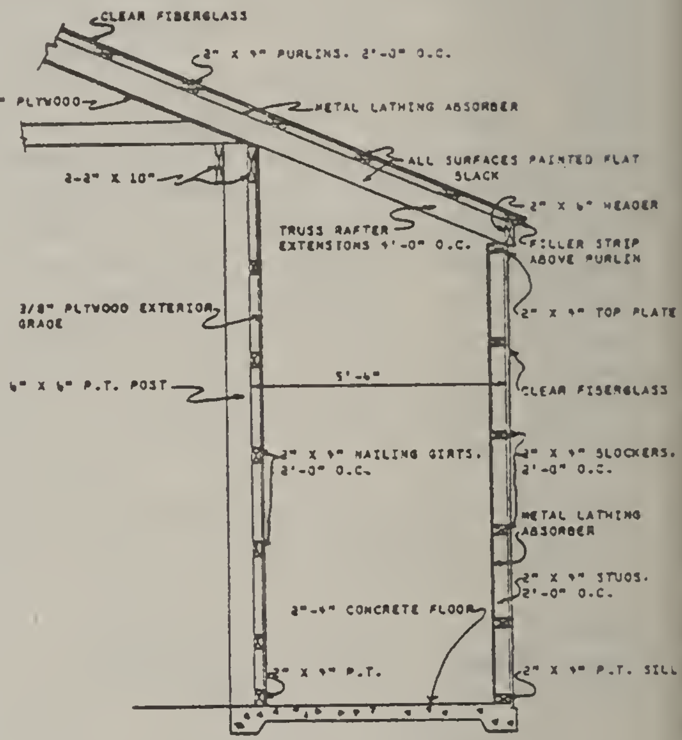


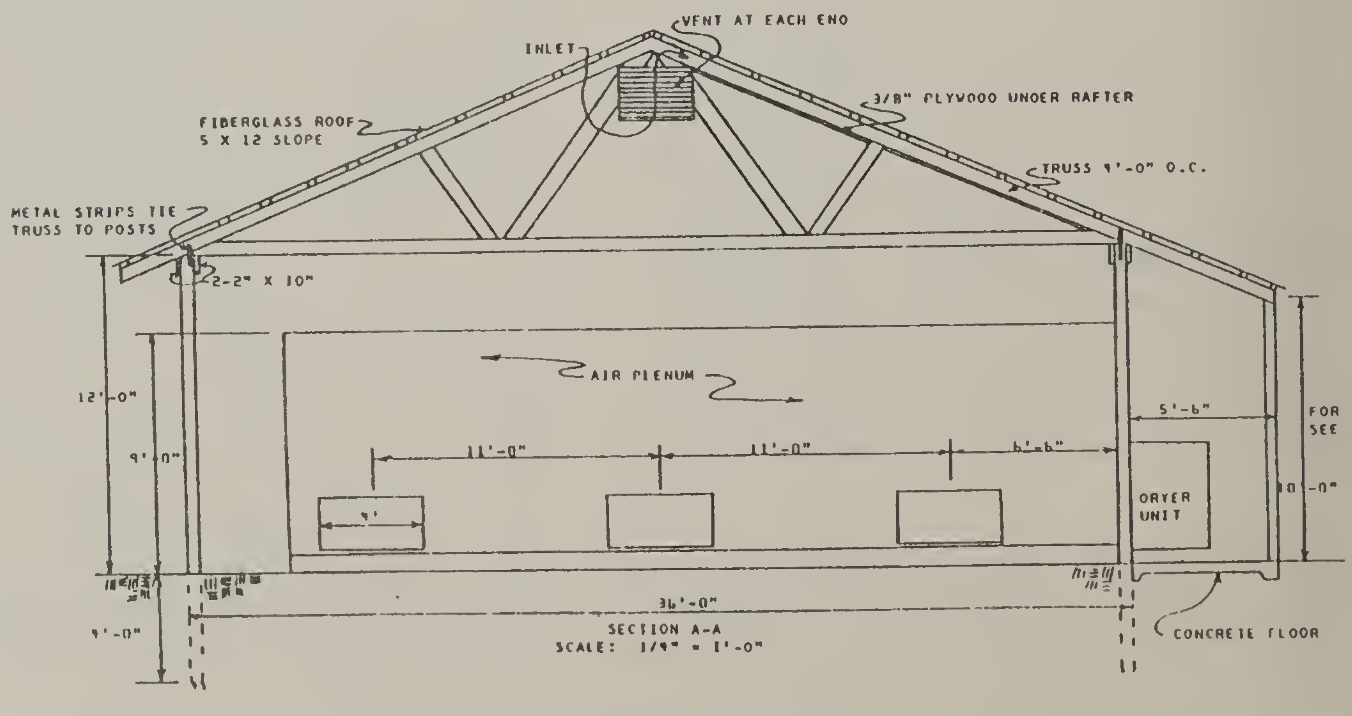


PLAN
SCALE: 1/8" = 1'-0"



SECTION USING STUD WALL CONSTRUCTION
SCALE: 1/2" = 1'-0"

NOTE:
USE CLEAR FIBERGLASS, MINIMUM 5 OZ/FT^2,
TREATED FOR ULTRAVIOLET RADIATION,
GREENHOUSE GRADE.



SECTION A-A
SCALE: 1/4" = 1'-0"

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SOLAR CROP DRYING SERIES

Agricultural Engineering

Multi-Purpose Crop Drying System with Two Solar Heat Collectors and Storage

A. J. Lambert and J. P. Harner, III

Solar water heating collectors and storage were added to provide supplemental heat for tobacco curing and grain drying on a southside Virginia farm. This report gives information on the construction and operation of the solar heat collection and storage system on the Roger Winn and Sons farm.

The development and testing of the solar assist crop drying system was supported by the Extension Division of Virginia Polytechnic Institute and State University, the U.S. Department of Agriculture, and the U.S. Department of Energy along with the farm cooperator.

THE FARM

The Winn farm is located south of U.S. Highway 58 one quarter mile east of the Henry-Pittsylvania County line near Axton. Table 1 gives a summary of crops produced and energy required to dry or cure these crops.

Table 1. Drying Energy.

Crop	Yield[1]	Moisture Contents: Harvested (%)	Moisture Contents: Stored (%)	Energy Required[2]	Total Energy Requirements (Million BTU's)
Corn	8,000 bu.	25	15	10,800 BTU/bu.	86.4
Soybeans	2,500 bu.	16	12	5,600 BTU/bu.	14.3
Wheat	2,750 bu.	16	12	5,600 BTU/bu.	15.4
Oats	2,000 bu.	16	12	5,600 BTU/bu.	11.2
Milo	7,500 bu.	20	12	6,400 BTU/bu.	48.0
Tobacco	60,000 lbs.			12,000 BTU/lb.	720.0

[1]Crop producton varies depending upon rotation.

[2]Estimations only.

Figure 1 shows the crop drying schedule and possible utilization time for the solar collectors. An estimated 895 million BTU's of fuel energy is required annually to dry or cure these crops. This is the equivalent of 9,948 gallons of LP gas.

The grain crops are dried in four 18' diameter 3,200 bu. metal bins. Grain is stored in these bins and two others located nearby. In the fall of 1980 a 40' x 80' shop was constructed with the ridge oriented S 75° W. The attic formed a solar collector which is used for shop heating and to assist with grain drying in two bins.

The cooperators have three bulk type tobacco barns which will hold up to 3,000 lbs. of cured tobacco each. Tobacco curing consumes 80% of the fuel used on the farm and the use spans a 5 to 6 week period. It is necessary to have accurate control of heat when curing flue-cured tobacco during color setting and early drying stages of the curing process. The temperature ranges from 90 to 160°F during the curing process with the high point in fuel usage at about 135°F.

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, and September 30, 1977, in cooperation with the U. S. Department of Agriculture. Mitchell R. Geasler, Interim Dean, Extension Division, Cooperative Extension Service, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061; M. C. Harding, Sr., Administrator, 1890 Extension Program, Virginia State University, Petersburg, Virginia 23803.

OBJECTIVES

- Design a practical and feasible solar water collector to provide supplemental energy for curing tobacco.

- Analyze the potential of solar water collectors for drying during the summer months when the solar radiation is more intense.

- Design a practical and feasible method of storing hot water for drying applications.

SYSTEM DESIGN

The distances between the various locations for uses of solar energy complicated the design. The nearest tobacco bulk barn is 140' from the shop with the solar attic. The two grain bins to be served with supplemental solar heat were 80' in the opposite direction. Also, the cooperator mentioned an interest in the future addition of a biomass burner to heat a common water storage system which could be used for home heating.

One solar water collector was placed in the attic of the shop. The 3,200 sq. ft. plywood ceiling is painted black on top to serve as an absorber plate. The water collector above it has an area of 600 sq. ft. (50' x 12') tilted slightly to the southwest. This orientation does not interfere with the solar attic air collector which serves as a supplemental air heater to two grain drying bins.

A second 24' x 28' solar water collector was placed on the roof of the 10,000 gal. heat storage pond. Both collectors permit solar energy to be collected and stored in the pond water throughout the summer and early fall.

The solar water collector in the shop attic is made of 1/2" copper pipe and a sheet metal absorber. The metal absorber is corrugated aluminum roofing painted with a flat black paint on the absorber (top) side. The copper tubing is placed in the corrugations of the roofing 8" apart and separated from the aluminum by heat transfer cement.

The water storage tank is a 10,000 gallon pond. The pond is 21' x 21' at the top and slopes down to 8' x 8' at the bottom. The slope of the pond sidewall is at approximately 45°. The pond is fully insulated below ground surface with polystyrene insulating board. The board is protected from moisture by a pond liner. The roof enclosure above the pond is made of 2" polystyrene insulation, an aluminum roofing absorber, and a clear fiberglass cover to form a solar collector. Water is pumped to a supply diffuser which dispenses the water along the roofing absorber. The water runs down the roof picking up heat and is drained back to the pond. The hot water is pumped through both collectors at a rate of 25 gpm when a thermostat senses sufficient heat gain for circulation. The water is pumped from the bottom of pond and then returned to the top. The distance between the pond and the attic collector is 110'. A 1 1/2" CPVC pipe, insulated by mineral fiber is used to transfer the water to and from the shop collector.

The solar heated water is pumped through another circulating system from the pond to heat exchangers located in the bottom plenums of two tobacco barns. The heat exchangers in each barn consists of 3 used automobile radiators. The fluid flow rate is 25 gpm (at 10' of head) and controlled by thermostat. Heated pond water is also pumped to a heat exchanger made from two automobile radiators located at the entrance to the fan unit to two grain drying bins.

The average radiation on the total collector surface for water heating from June through mid-September was projected at 2.46 to 1.90 million BTU's/day respectively. Anticipating 50% of the radiation will be transfered to the water, 1.23 to 0.95 million BTU's per day should be available to heat water, potentially replacing 13.6 to 10.5 gallons of LP gas daily. The amount of heat available to be utilized depends upon storage and plumbing heat loss, and heat exchanger efficiency.

COST

The cost of this system is difficult to estimate since a considerable amount of University personnel time was involved in its development and testing. A set of statements and bills shared by the cooperator indicates a cost of $13,021.57 which includes $2,100.00 for labor. The estimated cost was $8,075 including labor at $1,800. The total solar collecting area of 1,272 sq. ft. cost at least $10.23 per sq. ft.

PERFORMANCE

Most of the construction on the facility was completed in 1981 after the tobacco curing season. It was anticipated that the system would be used to assist with the curing of tobacco in 1982. Many problems developed which prevented use of the system until near the end of the 1982 curing season. The major problem was loss of prime by the water circulating pump to the tobacco barns. It was not solved until a hairline crack in the supply pipe was located and repaired. A second problem was the extreme evaporation of moisture off the surface of the storage pond. The surface was covered with an insulating material. A third problem was the low heat gain by a rubber hose type attic collector. The hose was replaced by copper tubing. A forth problem was related to use of the data logger for obtaining information on operation of the system. Two data loggers were damaged, apparently by lightning, at different times and had to be returned to the factory for repair.

Some information was obtained relative to temperature of heated water in the pond as indicated in Figure 1. Also, temperatures in the attic air and water mediums at certain time intervals were recorded. The maximum temperature recorded in the pond was 130°F. Up to 10°F increase in pond water temperature was recorded during the day with 2 to 3°F drop at night when no heat was used to supplement curing or drying.

ECONOMIC ANALYSIS

The system did not operate satisfactorily for a sufficient period to determine economic viability. If 50% of the energy available is collected and used, the savings would be more than $1,200 annually. This would make the investment of $13,000 marginal at best for tobacco curing only. Projected savings for crop drying and curing is 10.4%. To make the project economically feasible, the cooperator may have to resort to a supplemental biomass burner as was originally considered and use the system to heat his residence in addition to all other projected heat applications.

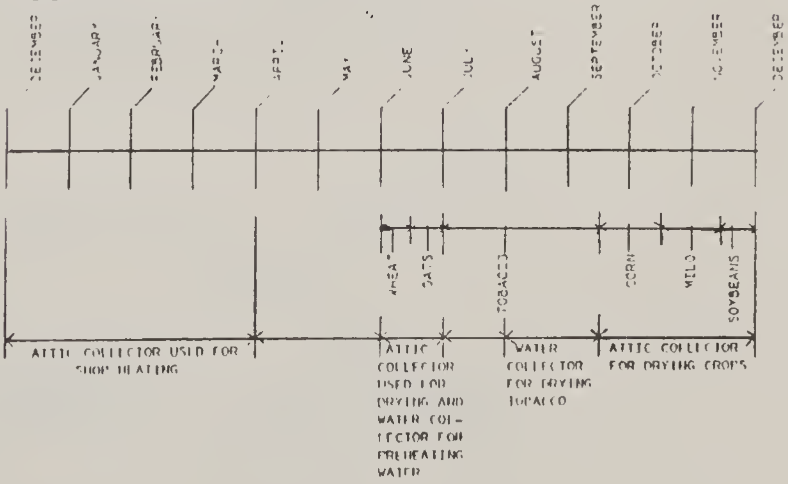

Figure 1. Crop Drying Schedule and Utilization Period of Attic Collector and Water Collector

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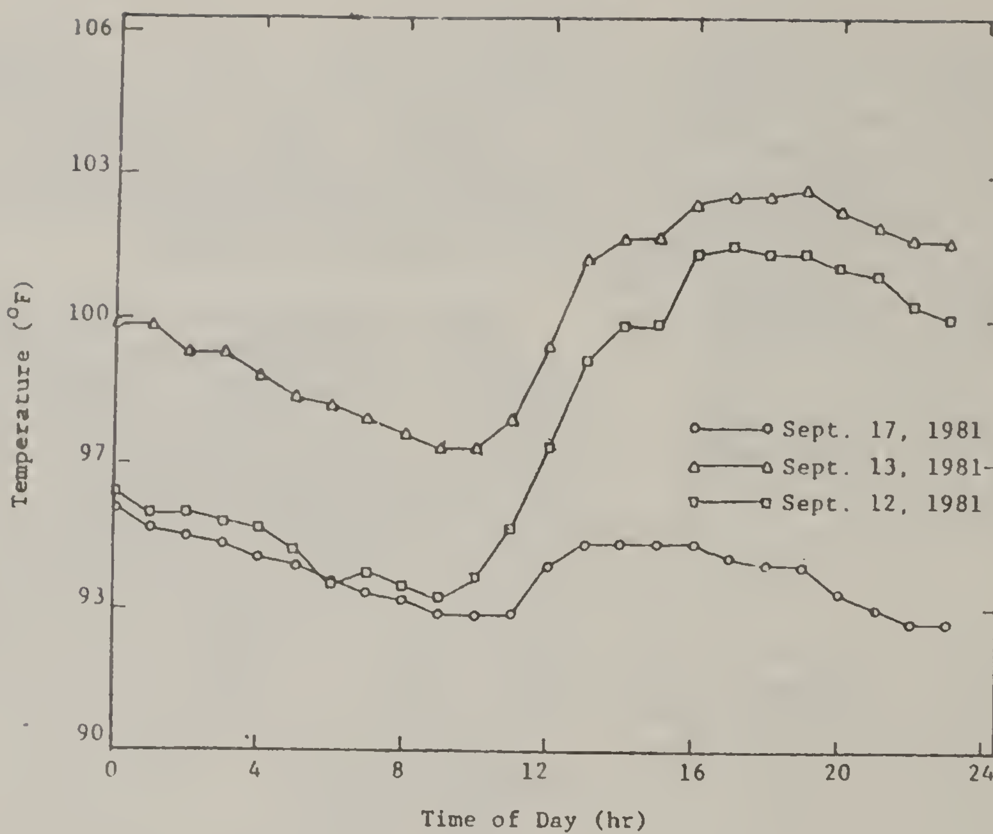
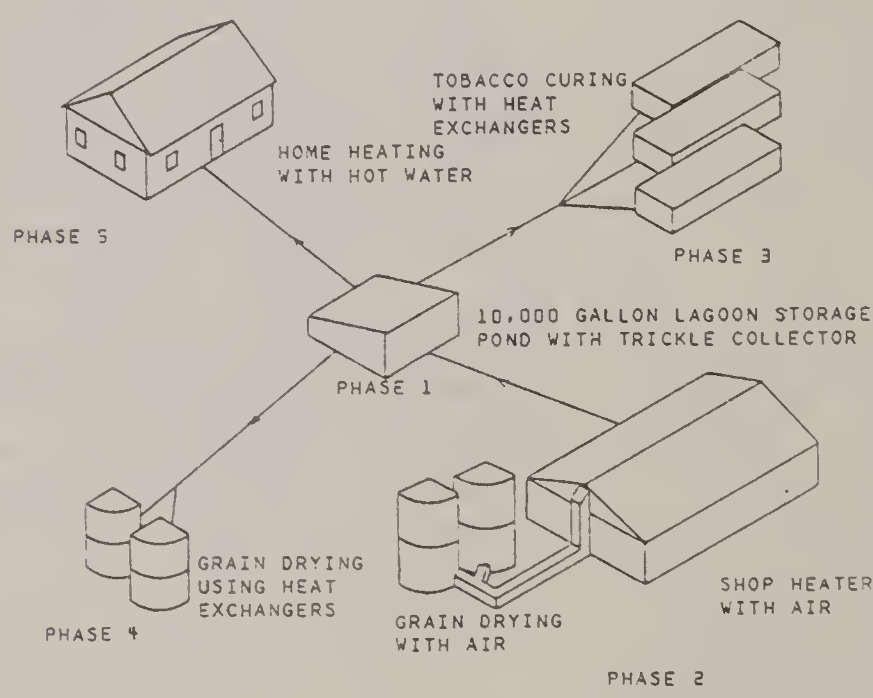
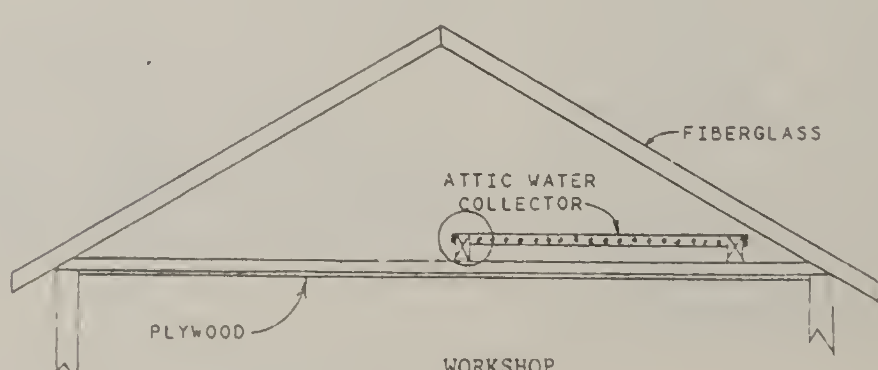


Water temperature in thermal storage pond.



Schematic of the five phase of the solar project



Layout of attic water collector located in workshop.

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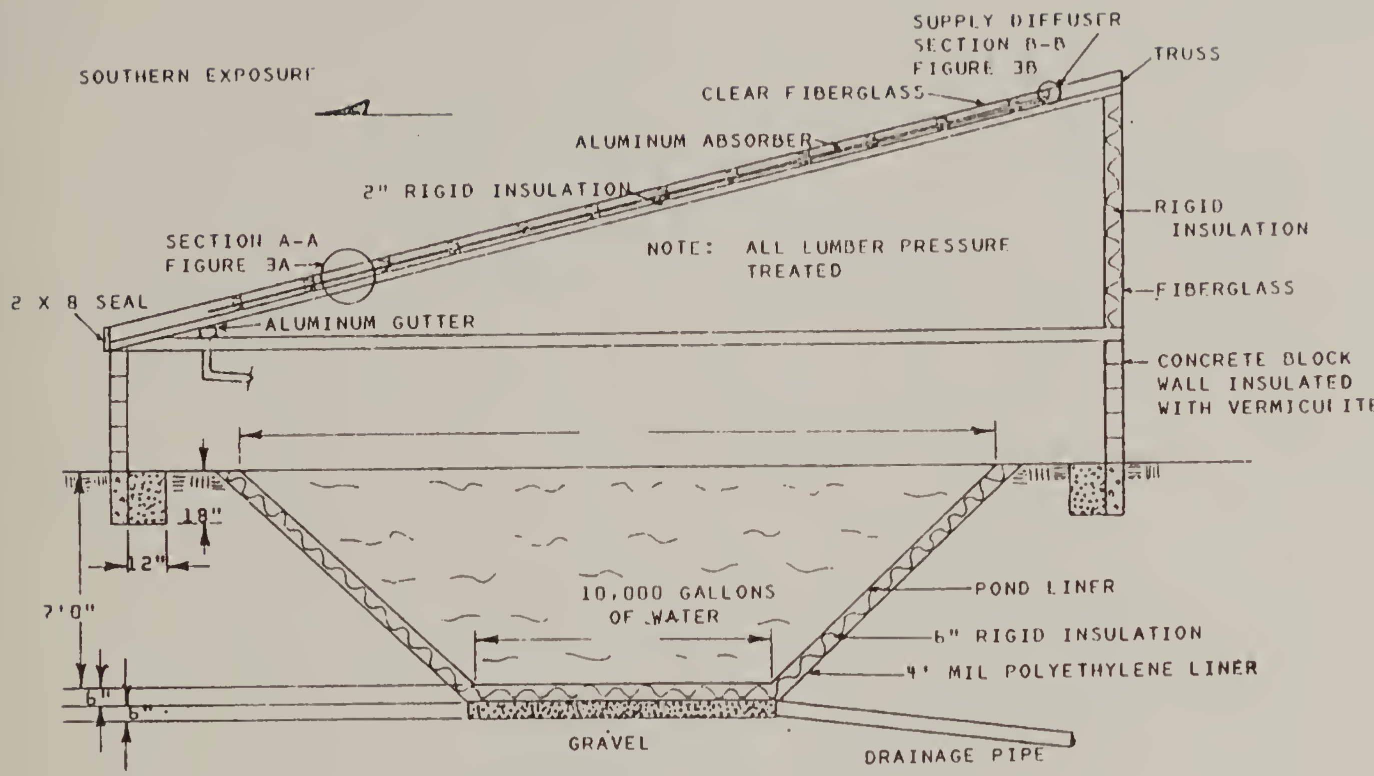
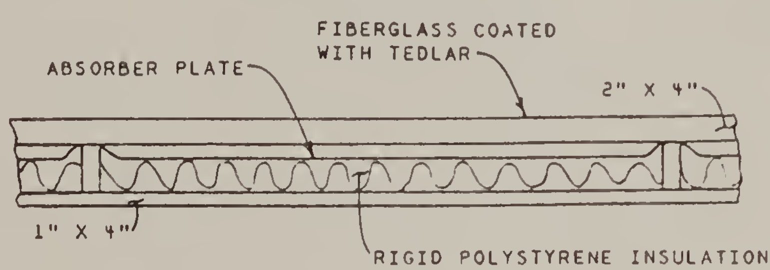
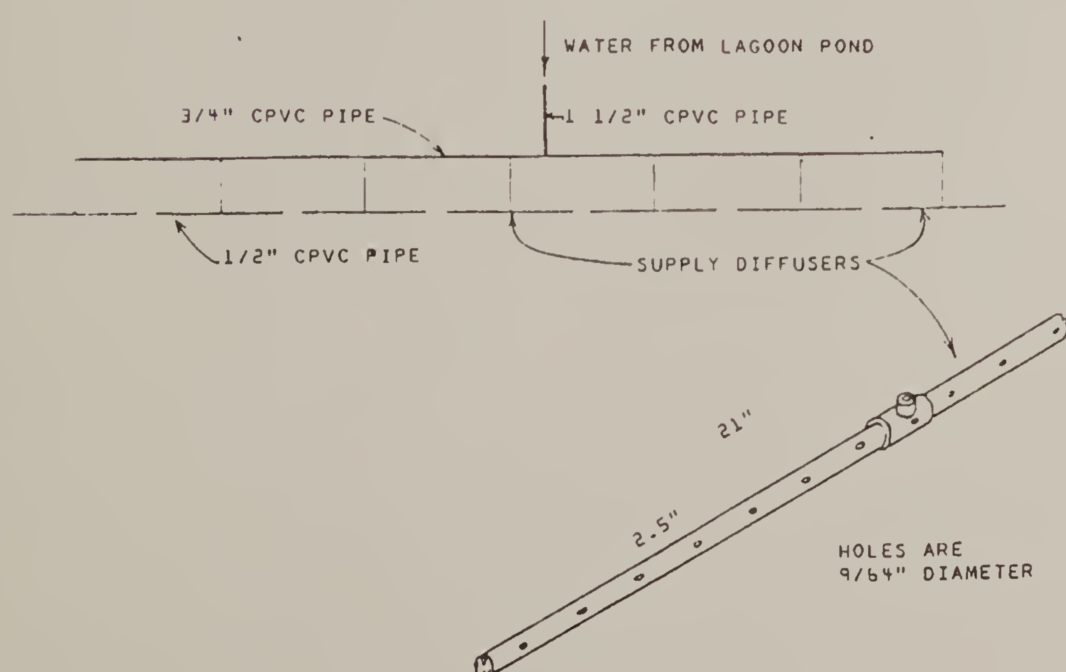


Lagoon storage pond and trickle collector.



Cross-section A-A.



Cross-section B-B

Appendix C

Sample
Material List
Estimated Cost
Total Building Cost
Actual Solar Cost
Cost Sharing Statement

VIRGINIA COOPERATIVE EXTENSION SERVICE

VIRGINIA TECH — VIRGINIA STATE

Blacksburg, Virginia 24061

November 6, 1981

Mr. Tom Hurd
Contracts and Grants Administration
301 Burruss Hall
Campus

Dear Mr. Hurd:

Enclosed is a statement for the total cost of construction of a solar collector for supplemental heat to assist with the drying of peanuts and grains on the farm of Kermit Francis, Route 1, Box 491, Boykins, Virginia 23827. I have bills and statements for the solar portion of the project in the amount of $3,436.01. We agreed to cost share 50 percent of the project within limitations. Therefore, a total payment of $1,718.00 is due Mr. Francis from the On-Farm Solar Drying of Crops and Grain Demonstration Project No. 231-11-110-002-3337191.

Thank you for your assistance.

Sincerely,

A. J. Lambert

A. J. Lambert
Extension Agricultural Engineer

pbc

Enclosure

Kermit Francis
Route 1, Box 491
Boykins, VA 23827

Construction of solar collector to provide supplemental heat for the drying of grains and peanuts.

Prescription Fertilizer and Chemical Co.	$1,037.56
Edwards Hardware Co., Inc.	17.10
Lawrenceville Building Supply, Inc.	291.20
Shands Hardware Center, Inc.	193.86
Franklin Concrete Products Corporation	812.01
Whitly Hardware	96.95
Sales Tax	97.95
Labor - James Vick	889.38
Total Cost	$3,436.01

Total Building Cost
Including Solar

Builders Supply Co. of Petersburg	$1148.89
Edwards Hdwe. $59.19 + 31.56	90.75
John R. Harrup	10.00
Lawrenceville Bldg. Supply	251.16
Miller Mfg. Co.	140.08
Franklin Concrete	2569.07
" "	441.02
" "	134.26
Shands Hdwe. 67.20 + 133.40	200.60
Whitley Hdwe.	100.83
Roy Combs - Wiring	932.26
" "	216.10
So. Metal Works	201.00
Southern States	75.42
Pres. [illegible] & Chem. Co.	2157.81
James Vick - Cabon	2933.14
E. E. Pittman	25.00
Total	$11,621.37

Dr. Lambert,
If you have any questions about any of these bills, please call me.
Thanks for all your help.

Windell Francis

Materials List

		Estimated Cost
<u>Fiberglass</u>		
26' x 50', roof		
10'-6" x 50', extended roof		
8' x 50', south wall	(2,418 ft^2)	$1,209
2 9'-8" x 10' , endwalls		
<u>Plywood, 3/8" (exterior grade)</u>		
26' x 50', roof	(1,900 ft^2)	$ 475
12' x 50', wall		
<u>Corrugated Metal</u>		
11'-6" x 50', wall	(575 ft^2)	$ 230
<u>Framing</u>		
8 - 10' 4" x 4", posts p.t.		
3 - 50' 2" x 4", girts, southwall		
6 - 50' 2" x 4", purlins, southwall		
12 - 12' 2" x 6", studs		
13 - 10' 2" x 6", truss extension		
2 - 50' 1 1/2" x 1 1/2" p.t. strips		
1 - 50' 1" x 10", vents		
10 - 10' 2" x 4", girts, endwall		
1 - 50' 2" x 8", girder		
1 - 50' 2" x 6", header		
1 - 50' 2" x 6", p.t. sill		
8 - 10' 4" x 4" p.t.		$ 42
19 - 10' 2" x 4"		38
45 - 8' 2" x 4"		72
12 - 12' 2" x 6"		53
14 - 10' 2" x 6"		50
5 - 8' 2" x 6"		14
1 - 10' 2" x 6" p.t.		4
5 - 8' 2" x 6" p.t.		20
1 - 10' 2" x 8"		4
5 - 8' 2" x 8"		17
	SUBTOTAL	$2,228

Materials List

	SUBTOTAL FORWARDED	$2,228
Framing (Continued)		
10 - 8' 1 1/2" x 1 1/2" p.t.		$ 15
2 - 10' 1 1/2" x 1 1/2" p.t.		4
1 - 10' 1" x 10"		5
5 - 8' 1" x 10"		20
	SUBTOTAL	$2,272
15% Miscellaneous (nails, caulking)		$ 341
	TOTAL	$2,613
Labor - 120 hours		$ 720
Total Estimated Solar Cost		$3,333

Appendix D

Educational Activities

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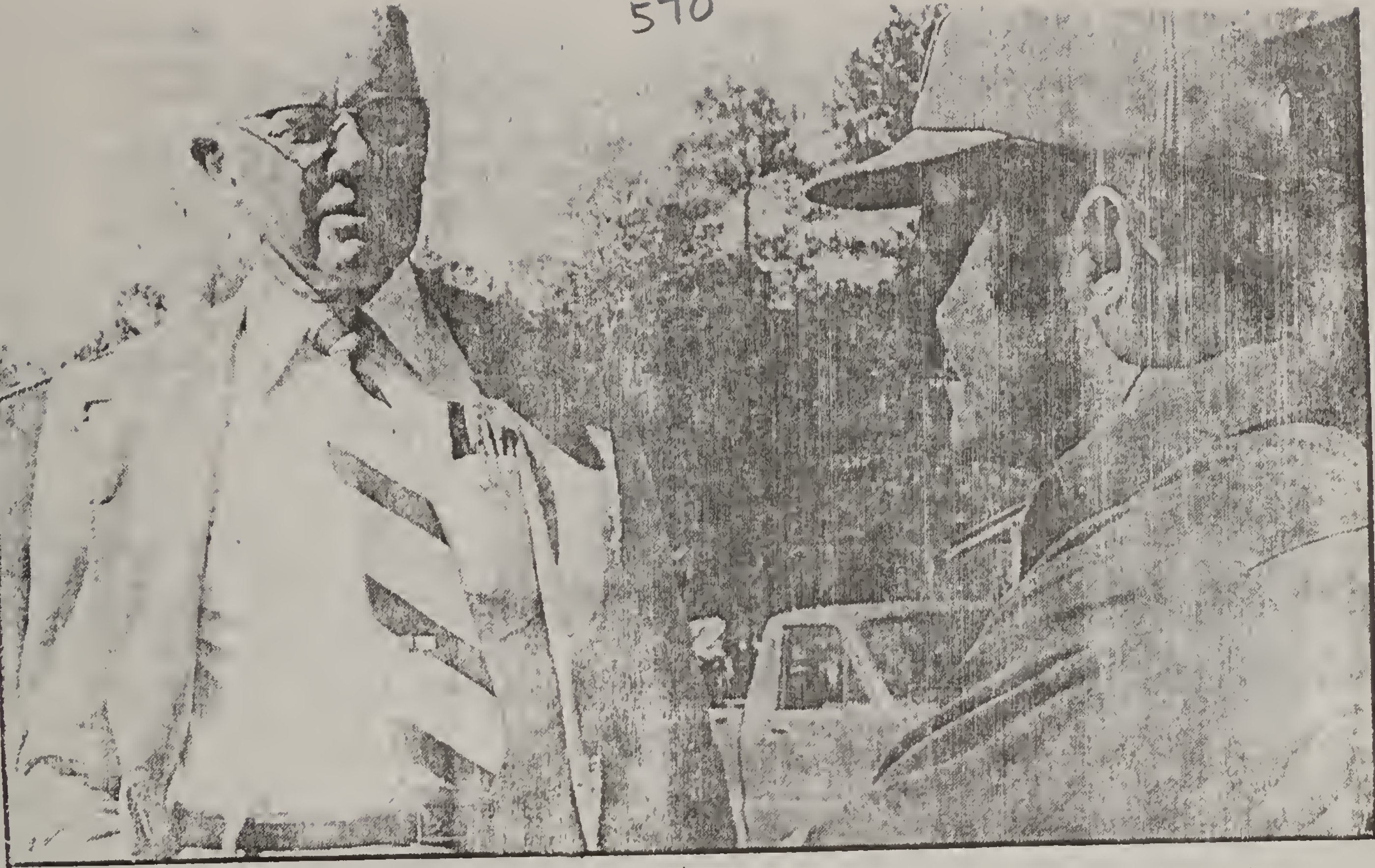


Kermit Francis talks with A.J. Lambert, Va. Tech extension agricultural engineer, about their new solar drying unit.

Near Capron

Solar Drying Saved Money In Fuel Costs

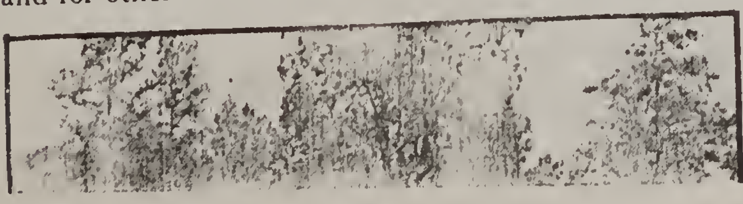
By ERNEST WRENN
Extension Agent
Southampton County

COURTLAND - "I was really pleased with the money we saved in fuel costs this fall with our new solar drying system," commented Kermit Francis recently. "I was also amazed how fast we were able to dry peanuts with this unit."

Kermit and his son Glenn who farm near Capron secured James Vick, a local contractor, to construct the building which can handle eight drying trailers. He gave them one fine job.

Best Unit of Kind

"The drying unit which the Francis' have is probably the best of its kind in the state" says A.J. Lambert, Va. Tech Extension Agricultural Engineer. "They incorporated all the features we feel essential for maximum efficiency to utilize the sun's ray to dry crops and for other uses."



I wondered if their peanuts might have dried too fast with the rapid turn around of the trailers. I asked Windell, Kermit's wife, to check out their grade sheets looking at the per cent of sound splits. She reported the average was less than 2%. This was good. We don't like to see splits exceed the 2% level. If they do, it indicates too rapid drying and lowering of quality.

Monitoring Instruments

Lambert said, "We had some instruments monitoring the Francis' unit and checking the efficiency of it. It looks like they were saving around 33% on the cost of fuel to dry this fall."

The Francis' record indicated they used 1.38 KWH of electricity per hundred weight to dry. At 5 cents per KWH, this was about seven cents per hundred weight of peanuts for electricity to dry.

Lambert and his colleagues from Va. Tech monitored two other solar units in the county this year. Both were set up in 1980.

30 Percent Savings

Robert Pulley and son Jeffrey, Ivor, have a six trailer drying building similar to the Francis' unit. It appears they had a savings of around 30% in energy cost this fall while utilizing solar energy to cut down on the use of propane gas for drying.

Best Unit of Kind

"The drying unit which the Francis' have is probably the best of its kind in the state" says A.J. Lambert, Va. Tech Extension Agricultural Engineer. "They incorporated all the features we feel essential for maximum efficiency to utilize the sun's ray to dry crops and for other uses."

Kermit and Glenn Francis' solar drying building.

Lambert continued, "Unfortunately for some reason we have difficulty in getting most farmers to agree to go all the way with our recommendations when building solar or other types of energy saving units. They want to change one or more features which often results in the unit not performing at maximum efficiency."

Panels for Efficiency

The Francis' building designed by Lambert is constructed so the air intake to the collector is on the underside of the roof along the peak. The air travels down the southside between clear corrugated fiberglass panels nailed on top of the rafter to 2 x 4 purlins. Plywood is attached underneath forming air channels down the roof. The area of the rafters, purlins and plywood exposed to the sun are painted black to absorb the solar energy. Also black metal lathing installed just under the fiberglass panels improves further the efficiency of the collector in trapping the sun's rays.

The heated air then comes off the roof drawn by the drying fans into a sort of greenhouse on the southside of the building made of the corrugated fiberglass panels. Here the air picks up more heat then is pulled into the air tunnel (plenum) by the two 7½ HP stacked fans. The solar heated air is forced down the air tunnel and out through the drying trailers.

Dried for Neighbors

Kermit and Glenn dried 636,299 pounds of peanuts in their eight trailers this fall. In addition they dried four trailer loads for a neighbor. According to their records, the cost was 49 cents per hundred weight for propane gas to dry peanuts.

Kermit commented, "This system really provides a lot of air to dry with. Even when we had all trailers attached you could place a handkerchief on top of any load and the air coming out of the trailer would lift it right up."

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Robert Pulley and son Jeffrey, Ivor, have a six trailer drying building similar to the Francis' unit. It appears they had a savings of around 30% in energy cost this fall while utilizing solar energy to cut down on the use of propane gas for drying.

Richard Cutchins, Black Creek area, with the assistance of Va. Tech Ag Engineers converted one of his drying trailer buildings to utilize solar energy. He told me recently, "My cost was much less for propane gas this year to dry peanuts in my drying building equipped to use solar energy. It worked out to 42 cents per hundred pounds using solar heat versus 65 cents per hundred pounds in a nearby drying trailer not using solar energy. I'm well pleased with the results."

Entire Roof Used

In Richard's setup the entire existing metal roof is utilized as the solar collector. Air channels were created under the roof by nailing plywood under the rafters. The solar heated air is pulled up through these channels between the rafters toward the roof peak into a plywood tunnel which carries the air through the building and down to the big fan on one end.

In addition to drying peanuts, Richard has been drying corn in the unit and solar energy has saved him considerable money in gas to dry corn.

Lambert commented, "With Richard's unit and with the others it's interesting we've found that a lot of the heat coming off the trailers during drying is being salvaged and recirculated right back through the system and used again."

Worthwhile to Construct

He concluded, "The more farmers use these units the more we can justify the cost of the solar equipment. During the winter if heat can be pulled off the roof to heat a farm shop or some other use, that makes it even more worthwhile to construct solar collecting equipment."

Certainly it appears solar energy has a place on many farms in the future to cut the cost of expensive petroleum based energy products.

Farmers demonstrate new ways to use the sun

A SUNNY PROPOSITION

"I'VE KNOWN FOR A LONG TIME that the sun generated a lot of heat," quips Roger Winn, wiping his brow for added emphasis as he gazes westward in the direction of rolling corn fields and the setting sun. "All we needed was some way to harness it."

That technique is now being perfected by Winn and some twenty-two progressive farmers throughout Virginia who agreed to lend their farms as solar demonstration sites for Virginia Extension projects.

"Somewhere along the line, someone had to experiment a little," says Winn, owner of Dogwood Farm, Henry County. "If any valid information was to be had, it had to be done right on the farm."

Extension specialists at Virginia Tech found strong interest in alternate energy systems in the late 1970s due to rising energy costs for one-farm operations. Many solar energy enthusiasts had produced paper studies and designs that painted a picture of great benefits and few problems in the use of solar energy in agriculture.

"Fortunately, the farmers who had to provide the money to construct the systems were considerably more cautious," notes Harold H. Hughes, Extension agricultural engineer and a leader of the solar livestock projects. "Before investing, they wanted to see research results and the technology demonstrated on Virginia farms."

Research had been conducted on several types of solar systems in a joint Department of Energy/USDA program. A number of promising designs were developed and evaluated as far as possible under that program.

"Crop drying and livestock housing were the two applications that seemed best suited to solar energy," says Andrew J. Lambert, Extension agricultural engineer and a leader of the solar crop drying projects. "Our basic strategy was to use the test/demonstration methods for Virginia."

Lambert initially designed a system that was constructed on the W.B. Robinson Jr. farm in Greensville County. The unit supplied partial heat for an otherwise conventional grain-drying shed. The savings in fuel costs offset the increased construction costs in three to five years. It is generally considered the first successful application of solar energy technology for an agricultural operation in Virginia.

Armed with cost-sharing funds from the federal government, both Lambert and Hughes set about choosing farmers to cooperate on their projects.

Today Hughes and research associate Dan Platt oversee eight livestock projects in seven counties (Greensville, Southampton, Henry, Buckingham, Northampton, Appomattox, and Rockingham). A majority of the projects involve swine farms, with the exception of a dairy operation and turkey facility.

The swine projects consist of preheating ventilating air in swine-farrowing units and using solar-heated water to warm the floor in farrowing units and nursery rooms. The turkey project uses solar-heated water for space heating in a brooding house. The lone dairy project heats water for washing udders and cleaning milking equipment.

A solar system erected on the farm of Appomattox County dairyman Dennis Torrence is in its second year of operation. Installed on the milking parlor roof, the system is doing just what it was designed to do—save money.

The system provides 30 percent of Torrence's requirement in the winter and 50 percent in the summer. The total cost of the solar addition was $2,800, half of which was paid by Torrence.

Southampton County swine producer Larry Whitley already had an interest in solar technology when he learned of the Extension projects.

"I felt it was the coming thing, so I was especially interested in having one of the demonstrations on my farm," he says. Although the system requires more attention than he envisioned, Whitley feels it is at least a step in the right direction.

On a normal day, the system provides about six hours of the total heating requirement on his 275-sow farm. "If the farmer had to pay the total cost of the system, I don't believe it would be feasible just yet," he says.

Using the sun to assist with drying crops has been another successful venture. Extension

agricultural engineer Andrew Lambert (who has gained a national reputation in the area) and graduate student/Extension assistant Joe Harner supervise fifteen projects in nine counties (Greensville, Southampton, Isle of Wight, Sussex, Loudoun, Henry, Bedford, Surry, and Fluvanna).

"We try not to oversell solar heat for crop drying, partly because we never know when we might get a rainy season," Lambert says. "But a good system does work when the weather is right."

And the weather has been right for William "Pete" Edwards, Isle of Wight County. His 20' x 45' collector is the only portable unit in Lambert's group and was built by Edwards in his spare time for about $5,000, half of which was funded by Extension.

"The use of solar heat cut my LP gas bill 15-20 percent last year in drying small grain, corn, milo, peanuts, and soybeans," Edwards states. "In winter, I move the collector to my farrowing house to help with heat bills there."

To store heat for nighttime and rainy weather use, a thirty-ton rock bed was built beside the twenty-four-sow farrowing unit. Solar heat saves 600 gallons of fuel each year on the farrowing house alone.

"We like to get multiple use out of a solar collector whenever possible," Lambert says. "The average usage we are getting in the projects is only sixty days each year."

A prime example of achieving maximum efficiency of a solar system can be found on the Roger Winn farm, Henry County, where average usage rises to five months each year. Winn's project, installed in a 3,200-square-foot machinery workshop he had already planned to build, uses air from within the shop building.

Solar collectors on the workshop roof heat the air, which is then drawn by fans from the shop to six storage bins containing corn, milo, wheat, oats, and soybeans. It also serves to heat the shop during winter months when machinery maintenance and repair is at its peak.

Winn, who is gradually turning control of his cattle, grain, and tobacco farm over to his sons, Marty and George, estimates his energy costs have risen 300-400 percent during the past five years. Results to date indicate these costs will be reduced substantially by the use of solar technology.

"I had also been concerned about the quality of grain when it was dried by conventional propane-fueled dryers," Winn says. When propane is used to power the dryers, there is a tendency for the propane to "get too hot and reduce the quality of grain at the bottom" of the bins, he notes.

Although using solar power requires a longer drying time, the problem of overheating becomes negligible, Winn finds.

To insure maximum usage of his system, Winn will experiment this year on solar curing of his twenty-three-acre flue-cured tobacco crop. "Tobacco is the most energy-intensive crop grown in Virginia," says Lambert. "Although we already know we can't cure the crop totally by solar, our goal is to supplement about 30 percent of the propane with it."

Solar-heated water from a 10,000-gallon lagoon storage pond will be pumped to three 150-rack bulk tobacco barns. Automobile radiators serve as heat exchangers in the innovative system.

Although Winn sank approximately $11,000 of his own money in the $15,000 solar project, he feels it was well worth it. "Something like this is really a small gamble when compared to the everyday risks of farming," he notes.

In Southampton County, data show that a solar collector Kermit Francis built as part of a new drying shed cut his crop-dryer fuel bills by 32 percent. "Half of his savings comes from solar energy and the other half from partial recirculation of warm air that's normally lost during the drying process," Lambert explains. "This was a benefit we didn't originally anticipate when we designed the structure."

Kermit and his son, Glenn, farm near Capron and were amazed at how fast they were able to dry peanuts with their new unit. A good quality product was also maintained with little damage to peanuts due to overheating.

"The system built by Francis is probably the best of its kind in the state," says Lambert. "It incorporates all the features we feel essential for maximum efficiency to use the sun's rays to dry crops and for other uses."

Lambert advised Francis to position the building so the solar-heat collection room faces due south, as does part of the building roof, which also traps the sun's rays. Fans pull air from under the roof into the heat collection room where it picks up more heat before being forced through an air tunnel and out through the drying trailers.

Working with Lambert, Francis also got cost-sharing funds of $1,700 (half the total cost) for the solar collector on his new building.

Kermit and Glenn dried 318 tons of peanuts in their eight trailers last fall. In addition, they dried four trailer loads for a neighbor. According to their records, the cost was 49¢ per hundredweight for propane gas to dry the peanuts, compared with the normal costs of 70¢ to 75¢ per hundredweight. Other farmers with demonstration drying projects showed even better results.

Kermit comments, "The system really provides a lot of air to dry with. Even when we had all trailers attached, you could place a handkerchief on top of any load and air coming out of the trailer would lift it right up."

Lambert notes, "The more that farmers use these units, the easier it is to justify the cost of the

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solar equipment. If the heat can be pulled off to warm a farm shop or serve some other purpose, that makes it even more worthwhile to construct solar-collecting equipment."

Both Lambert and Hughes agree that the benefits reaped from the solar projects have been and will continue to be great. "A great deal of information and experience has been gained that will be used in future alternate energy programs," Hughes says. "In particular, we have identified several instances where solar has a reasonable prospect of success and others where another alternate technology appears to be an even better choice."

The major intangible benefit Lambert and Hughes cite is the good working relationship the Extension Service has developed with a group of the most progressive farmers in the state.○

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Sun power, peanuts

By JOHN SIZEMORE

As solar heating slowing comes of age, it reaches into many areas, including agriculture. You can see this in Greensville County, where two farmers use the power of the sun to dry peanuts.

William "Doc" Robinson has had his solar-heated drying shed operating for several years, but Benjamin Veliky is operating his for the first time, and in conjunction with a Va. Tech experiment on the new process.

Veliky built the shed, which is very much like a conventional drying shed, at his expense. Then Andy Lambert, a Tech specialist, came in with an array of electrical gadgets to monitor the workings of the operation. Later, data from Veliky's first drying season will be used to design other solar operations.

Don Harvey, a local extension agent, keeps track of the instruments all over the drying shed.

"It's really the same construction as an ordinary drying shed except for the solar collector," said Harvey.

One eight-foot section of the shed is closed in to form the solar collector. Sunlight enters through fiberglass panels on the roof and walls. Heat builds up, aided by the black interior of the collector, and a blower sucks up the hot air and sends it on to dry the peanuts.

The blower is the same as you would find in a conventional system. It also has a conventional gas heater attached for use when the sun does not provide enough heat.

Hot air from the blower goes into a long channel called the plenum. From the plenum the air is piped into up to six trailers of peanuts. The air enters in the bottom of the trailer, drying the peanuts as it rises.

When the warm air reaches the top of the trailors and rises to the ceiling, it enters a special vent, from which it is sucked back into the solar collector to be recycled. To aid in this recycling, Lambert has added plastic curtains to

available during the day. All of that data will be used for research at Va. Tech. A grant from the Virginia Peanut Growers Association will pay for the research part of the local project, Harvey said.

Does it work? Well, when you enter the solar collector, right away you know something is working. With the outside temperature about 60 degrees, the sun warms the air inside to about 80 degrees.

The planners don't expect the solar collector to replace the gas heater, but just to supplement it, thus saving gas. Harvey said it's too early to tell just how much Veliky is saving. But Robinson estimates that by using the sun he saves about 50 percent of what drying with the conventional system would cost.

COLLECTOR-- --Don Harvey checks the temperature inside the solar collector of the peanut drying shed. To his right is the blower which collects the air w...

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Solar Power Experiments Planned For Farms In State

BLACKSBURG, Va. — The sun may shine a bit brighter for Virginia farmers in the future with the recent announcement of a grant awarded to the state for solar research on farms.

Virginia was selected as one of nine states to participate in on - farm demonstrations using solar heat for drying crops and grains.

According to Andrew J. Lambert, Extension specialist in agricultural engineering at Virginia Tech, the Department of Energy awarded $110,000 to the state for use with the solar projects. The money will be allocated over a three - year period.

The solar additions will be used to dry grain, hay, tobacco and peanuts on 10 Virginia farms selected as demonstration sites.

Once the selection process has been completed, Extension specialists in the departments of agricultural engineering and agricultural economics at Tech will work with the individual farmers to design facilities and study the economic feasibility of each project.

"Our goal is to get multiple use of the solar collectors whenever possible," Lambert said. "In some instances, they will be used to heat livestock facilities as well as dry crops."

A portion of the grant money will be used to pay one - half of the costs of the solar addition with the farmer picking up any additional costs. Remaining funds will go toward the purchase and installation of equipment and monitoring test results.

Lambert estimated that between $1,000 - $3,500 wi spent per collector for the age drying facility. The d systems will include tra bins and portable collectoı tems with an estimated age annual usage of 60 days

"This grant money will us to try techniques used i search and see how adap they are to our situation he Virginia," Lambert said. will be able to get a better nomic handle on the valu solar energy and its plac Virginia farms."

The Virginia Tech agric ral engineer said it was alı known that tobacco prod could realize a 9 to 15 pe energy savings when c flue - cured tobacco by sol ergy.

"There also is the potent save one - third of the re costs of drying peanuts grains when harnessing sun's power," Lambert sai

The demonstration fac are expected to be in oper by this fall and will be us educational purposes by tl operative Extension Serv tours and field day prograı

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Eugene W. Taylor, Fre
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SOLAR FARM RESEARCH

The sun may shine a bit brighter for Virginia farmers in the future with the recent announcement of a grant awarded the Old Dominion for solar research on farms. Virginia was selected as one of nine states to participate in on-farm demonstrations using solar heat for drying crops and grains. The Department of Energy awarded $110,000 to the state for use with the solar projects. The money will be allocated over a three-year period.

The solar additions will be used to dry grain, hay, tobacco and peanuts on 10 selected Virginia farms as demonstration sites. Once the selection process has been completed, Extension specialists in the departments of agricultural engineering and agricultural economics at Tech will work with the individual farmers to design facilities and study the economic feasibility of each project. The goal is to get multiple use of the solar collectors whenever possible. In some instances, they will be used to heat livestock facilities as well as dry crops.

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Estimates are that bet $1,000 and $3,500 wil spent per collector foı average drying facility. drying systems will inc trailers, bins and port collector systems witl estimated average an usage of 60 days. This g money will allow resea ers to try techniques us research and see how ac able they are to our situa here in Virginia. They wi able to get a better econ handle on the values of s energy and its place on V ginia farms.

It is already known th tobacco producers coul realize a 9 to 15 percent energy savings when curing flue-cured tobacco by solar energy. There also is the potential to save one-third of the regular costs of drying peanuts and grains when harnessing the sun's power.

The demonstration facilities are expected to be in operation by this fall and will be used for educational purposes by the Cooperative Extension Service in tours and field day programs.

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WE... NTROL
IN... GRAIN

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G en pa foı h su be fr nl

... Mrs. William E. Haywood, Jr. of Portsmouth, Virginia.

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Solar Projects Set For 10 Host Farms

Special to The Progress

BLACKSBURG — The sun may shine brighter for Virginia farmers in the future because of grants awarded the Old Dominion for solar research on farms.

Virginia and eight other states have been given money by the Department of Energy to demonstrate and to study the use of solar heat in drying crops and grains on farms.

"This grant money will allow us to try techniques used in research and see how adaptable they are to our situation here in Virginia, " Andrew J. Lambert, extension specialist in agricultural engineering at Virginia Tech, said. "We will be able to get a better economic handle on the values of solar energy and its place on Virginia farms."

The $110,000 DOE grant will be allocated over a three-year period, Lambert said.

The solar additions will be used to dry grain, hay, tobacco and peanuts on 10 Virginia farms.Once the farms have been selected, specialists in agricultural engineering and economics at Tech will work with farmers to design the facilities and to study the economic feasibility of the projects.

Costs of each of the 10 solar additions will be split between the farmers and DOE. Remaining DOE funds will be used for the purchase and installation of equipment and for the analysis of test results.

Lambert estimated that from $1,000 to $3,500 will be spent to build the average facility, including trailers, bins and portable collector systems.

"Our goal is to get multiple use of the solar collectors whenever possible. In some instances, they will be used to heat livestock facilities as well as dry crops," Lambert said.

The demonstration facilities are expected to be in operation by this fall and will be used for educational purposes by the coooperative extension service in tours and field day programs.

Tobacco Energy Conference Planned

DANVILLE — Tobacco has its roots deeply embedded in the history of Virginia. And, according to the latest data at Virginia Tech, the Old Dominion ranks fourth in production among the 18 tobacco-producing states in the United States.

Along with this rise in rank has come an increase in he amount of fuel oil used in curing flue and fire-cured tobacco — the two major types grown in Virginia.

According to Andrew J. Lambert, Extension specialist in agricultural engineering at Virginia Tech, it takes about seven million gallons of fuel oil or LP gas to cure the state's tobacco crop annually. Fuel oil jumped from 49 cents per gallon in 1978 to 98 cents in 1980 and is continuing to rise. The price per gallon of LP gas is generally about two-thirds that of fuel oil.

"The cost of fuel and electricity used to cure a barn of tobacco went from $125 to $245 in three years, a 96 percent increase," Lambert noted. "We can't do anything about the soaring prices, but we can do something about the amount and kind of fuel we use."

And that's why Lambert and several other Tech Extension specialists have planned a Tobacco Energy Conference for Tuesday and Wednesday, Feb. 24-25. The King of the Sea Restaurant in Danville will be the site of the conference designed for tobacco farmers, equipment and service suppliers, educators and industry representatives.

"We have assembled a group of quality speakers who spend a large part of their time studying and testing ways to reduce energy use or use it more efficiently in t production," Lambert stated. "Mos both research and on-farm experienc energy use on tobacco farms in G South Carolina, North Carolina Virginia."

Among the topics to be discussed ar design and curing efficiency, loadi barn, the use of chemical coloring a the curing process, air flow, harv systems, structural heat loss, al energy sources (solar, alcohol, woo mass heat sources), energy tax credit the economics of energy conserv techniques.

The impressive group of speakers cc of authorities on every aspect of to production from Virginia Tech, Cl University, and North Carolina University.

All Virginia tobacco producers ar terested persons are urged to attend registration is necessary, A tw registration fee of $20 includes two luncheons, refreshment breaks, spea fees and a copy of the proceedings. A on fee of $14 includes one lunc proceedings, speaker's fees and refresh breaks.

Requests for lodging should be directly to the Riverside Drive Holiday Danville, Va. 24541. For addition formation on the conference, co Andrew J. Lambert, Seitz Hall, Vir Tech, Blacksburg, Va. 24061 or call (703 6089.

Farmer: John S. Copeland
Rt. 1, Box 690
Windsor, Virginia 23487

THE CROPS

Crops grown at Mr. Copeland's farm site include 62 acres of corn, 41 acres of peanuts, and 20 acres of soybean. A 40' by 42' 6-trailer drying facility (ridge line running S14 W) equipped with an LP gas drying unit has been used for several years to assist in the drying of these crops. Mr. Copeland typically dries 7,750 bushels of corn during the last half of August and all of September; 164,000 pounds of peanuts in October; and 700 bushels of soybean in the first half of November. The energy required to dry these crops is estimated to be 186.0 million BTU's (equivalent to 2,067 gallons of LP gas).

A solar collector will be added to the existing system in order to preheat the air entering the LP gas drying unit.

THE COLLECTOR

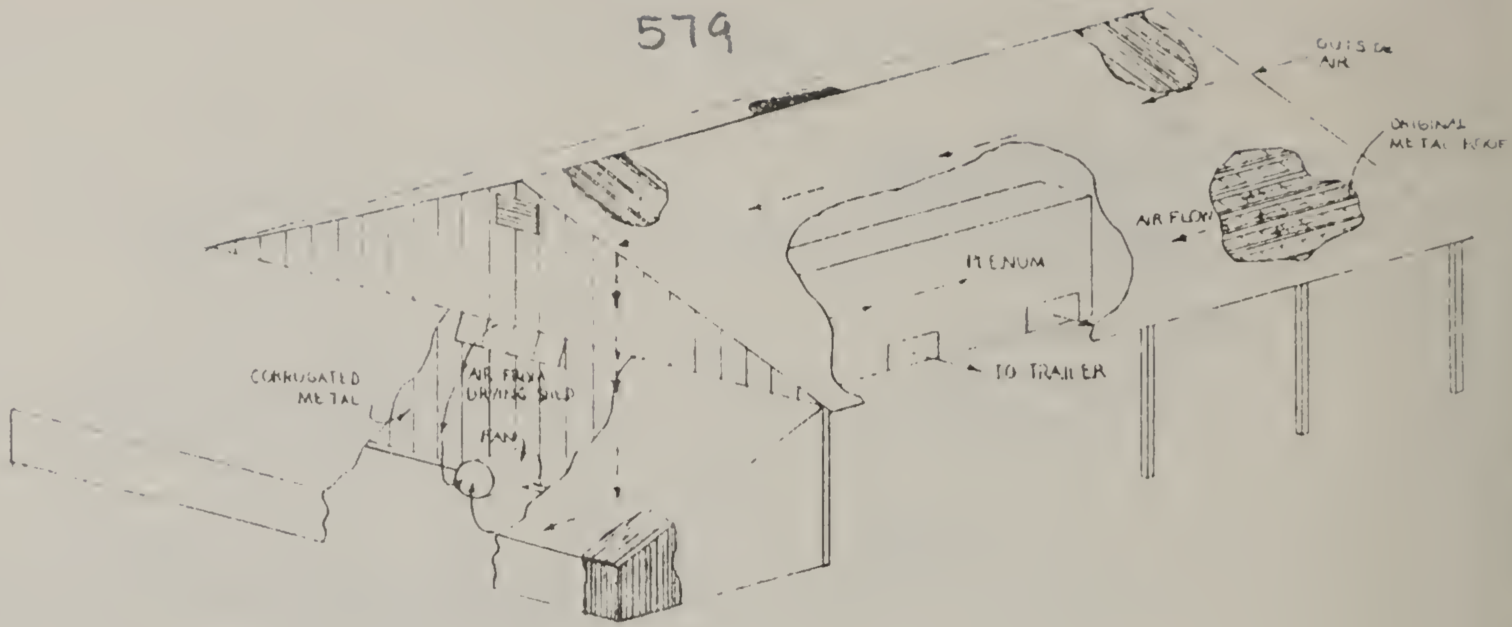
Both slopes of the roof of the drying facility will be converted to a covered-plate solar collector, utilizing an area of 2,024 sq. ft. An additional 1,136 sq. ft. of collector will result from the roof, side walls, and endwall of an attached shed that encloses the drying fan. This integrated shed will be located on the end of the drying facility that faces S14 W.

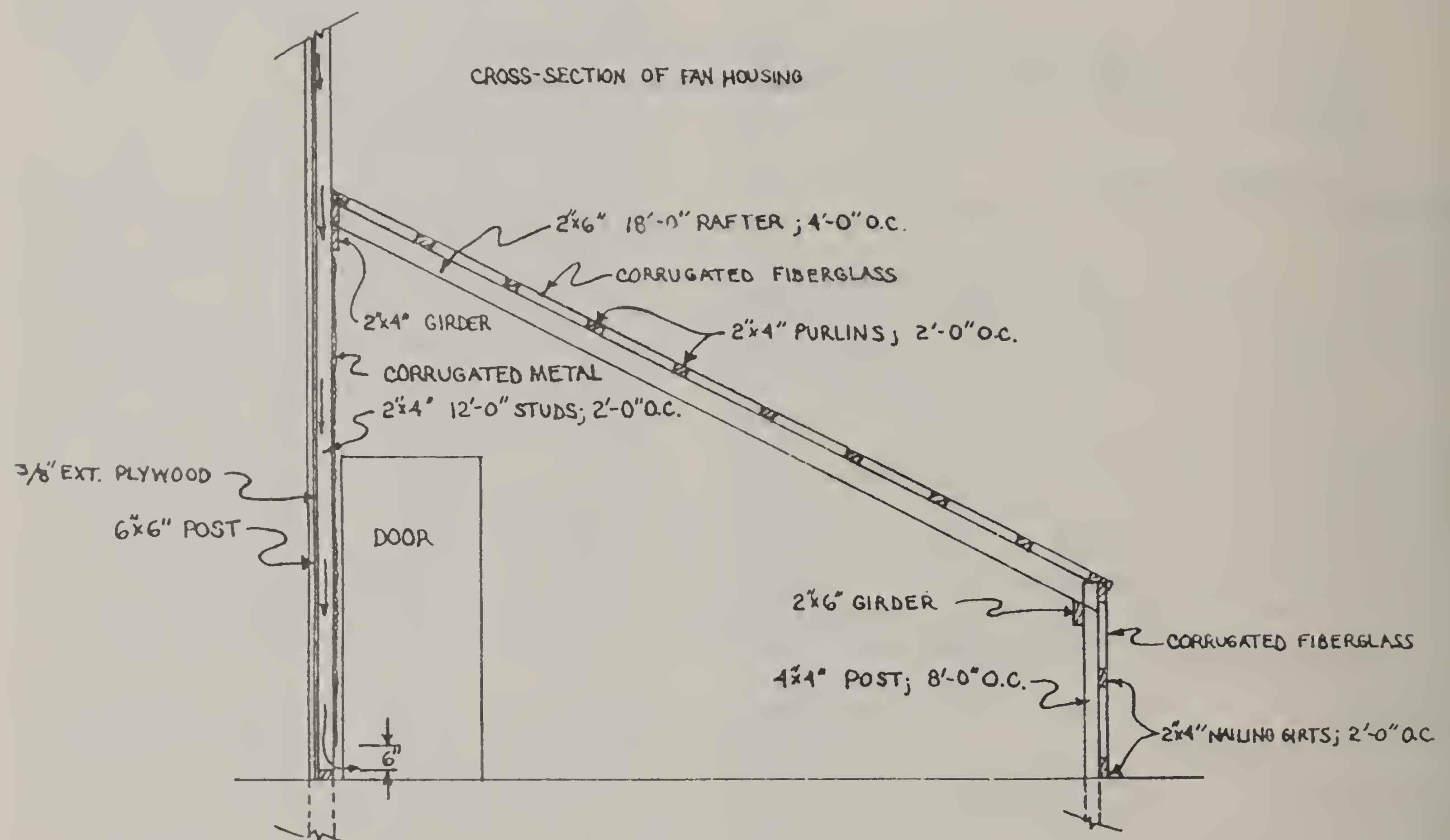
The roof collector on the drying facility consists of a clear corrugated fiberglass cover over the existing roof, which will be painted black. The outer surfaces of the integrated shed will be covered with the same fiberglass covering. An absorber will be constucted in the integrated shed from black corrugated metal sheathing that extends down to 6" above the ground. The absorber will be separated from the drying facility wall by a 4" air channel.

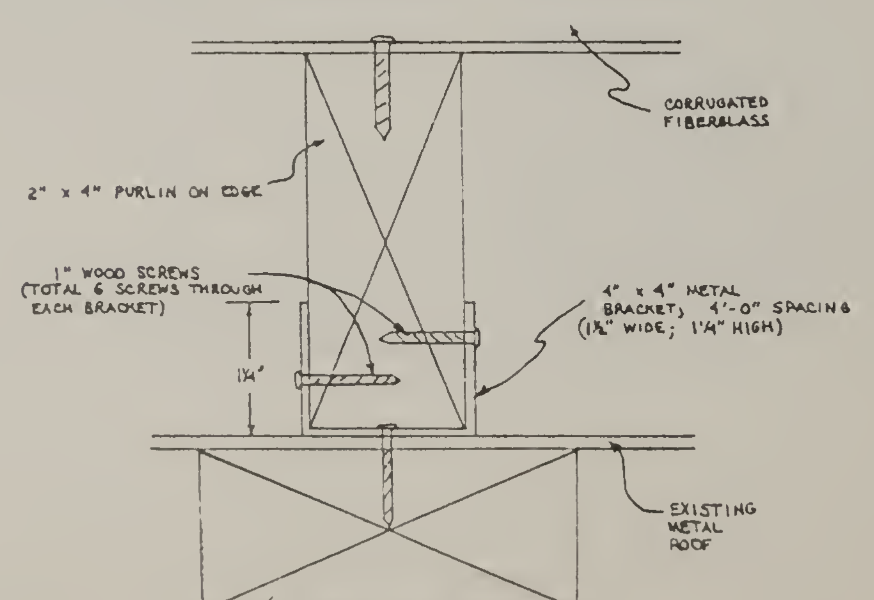
Air enters the system at the north end of the roof collector drawing ambient air from outside the drying shed. The air should receive heat from the absorber as it is brought parallel to the ridge line. The fan in the drying unit will be used to pull air through the roof collector, across the metal absorber in the integrated shed, and into the collection area. Air is then forced down a plenum chamber and into drying trailers attached to the plenum.

The air velocity through the roof collector and between the metal absorber and plywood wall will be maintained at 800 to 1,000 feet per minute. An additional inlet will allow the remaining airflow required by the drying unit to enter the collection area from inside the drying shed.

The total cost (including labor) for the 3,160 sq. ft. solar collector is $3,811.00, or $1.21/sq.ft. The collector is expected to save 38% of the fuel normally required to dry Mr. Copeland's crops. This suggests an annual savings of 787 gallons of LP gas.







BRACKET SECTION

Farmer: Robert Pulley
Rt. 1, Box 115
Ivor, Virginia 23866

THE CROPS

Crops grown at Mr. Pulley's farm include 100 acres of corn, 62 acres of peanuts, and 65 acres of soybean. The corn crop is dried in a bin dryer with a stirrer. A 36' by 48' 6-trailer drying facility (ridge line running N76 W) equipped with an LP gas drying unit has been constructed to assist in the drying of peanuts and soybeans. Mr. Pulley plans to dry 217,000 lbs. of peanuts and 2,275 bushels of soybean in a September to mid-November drying period. An estimated total of 142.9 million BTU's of energy (equivalent to 1,588 gallons of LP gas) are required to dry Mr. Pulley's crops. In the future, the trailer drying facility may be used to dry corn in trailers providing that it can be shown to be a viable cost-reduction alternative.

A covered-plate solar collector was designed to preheat the ambient air before it is drawn into the LP gas drying unit.

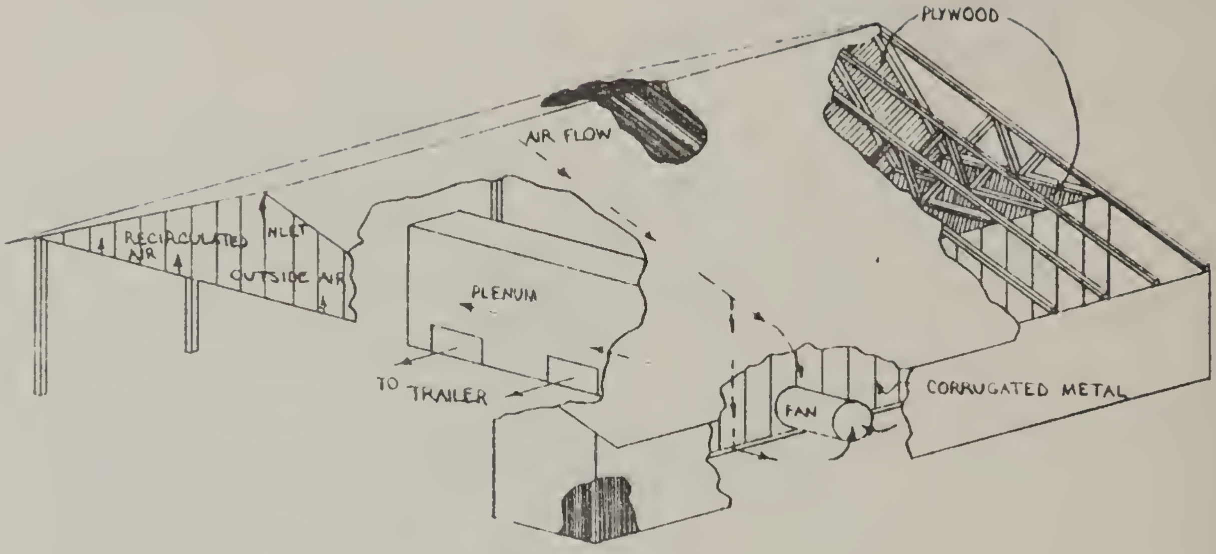
THE COLLECTOR

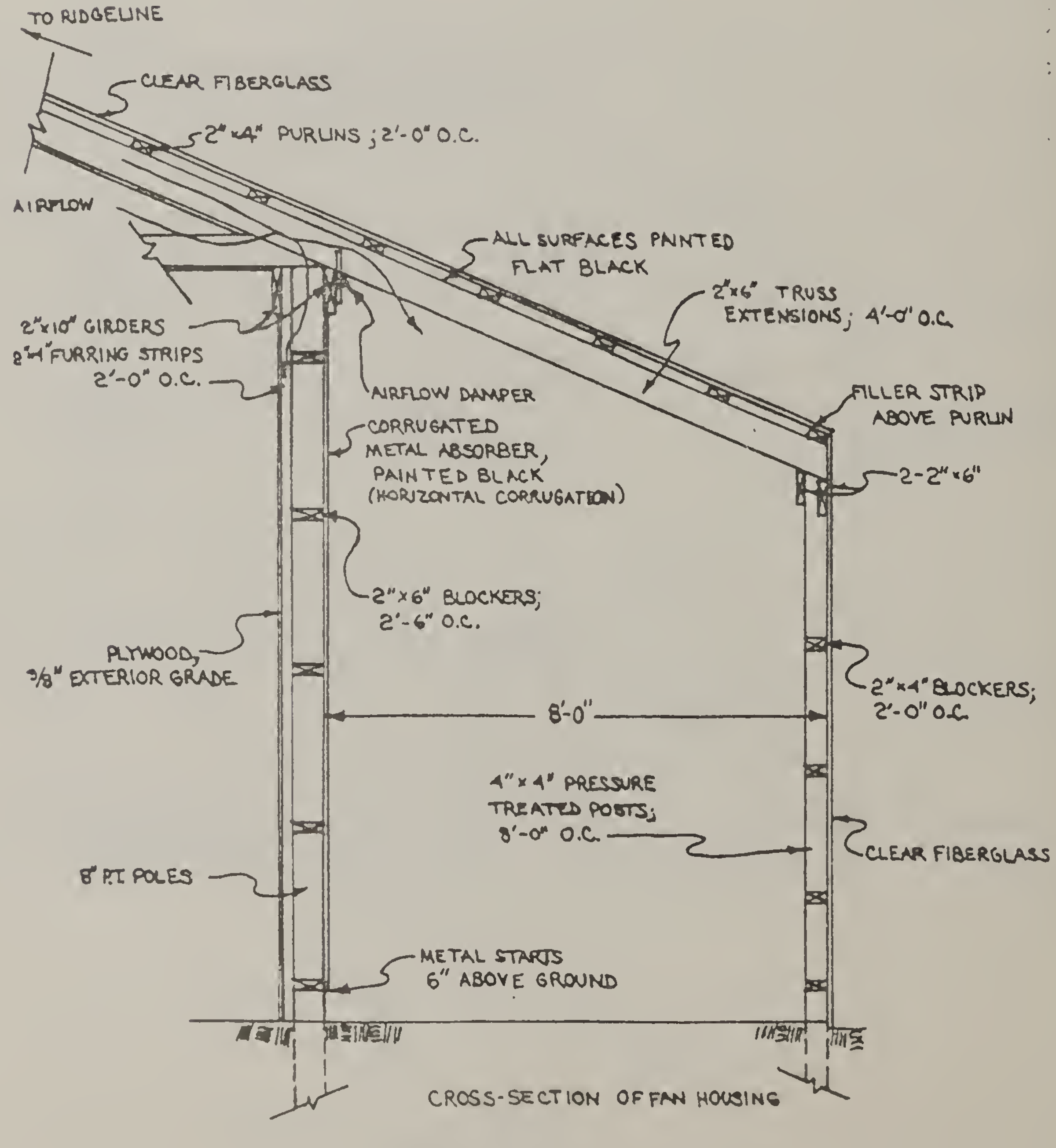
A 1,352 sq. ft. covered-plate solar collector will be constructed on the south roof of the drying shed and on the roof of an adjacent collection area housing the fan. An additional 581 sq. ft. of collector will result from the endwalls and the vertical south wall of the collection area.

The roof collector consists of a clear corrugated fiberglass cover over a flat black corrugated sheet metal absorber. Using 3/8" plywood , an additional absorber is oriented in the rafters to form an attic-like space. The cover plate on the outer walls and roof of the collection area will be constructed of the same corrugated fiberglass. An additional absorber in the collection area will be a corrugated metal sheathing extending down to 6" above the ground line and separated from the drying facility wall by an 8" air channel.

The air inlet will be located underneath the ridge of the drying shed to allow partial recirculation of the drying air. A portion of the air entering the collection area will be directed by an adjustable damper so that it passes over the corrugated metal absorber in the fan housing unit. The preheated air will be forced by the fan into a plenum and then into drying trailers. Approximately 30,000 cfm of air will be moved through the collector at 1" of static pressure.

The total estimated cost (including labor) for the 1,933 sq. ft. of solar collector is $3,261.00, or $1.69/sq.ft. The collector is expected to save 21% of the fuel normally required to dry Mr. Pulley's crops (a savings of 334 gallons of LP gas annually).





CROSS-SECTION OF FAN HOUSING

Farmer: Ben Velicky
Rt. 3, Box 320
Emporia, Virginia 23847

THE CROPS

Crops grown at Mr. Velicky's farm include 107 acres, of peanuts, 60 acres of corn, and 15 acres of soybean. A 36' by 48' 6-trailer drying facility with a ridge line running east-west has been constructed to assist the drying operation. The drying period extends from mid-August through November. During this time, approximately 374,500 lbs. of peanuts , 3,960 bushels of corn, and 420 bushels of soybean are dried. An estimated 269.9 million BTU's of energy (equivalent to 3,000 gallons of LP gas) are required to dry Mr. Velicky's crops.

A covered-plate solar collector was designed to preheat the ambient air before it is drawn into an LP gas drying unit. An additional structure , interfacing the south wall of the drying shed, shall house the drying unit and serve as a collection area for the preheated air.

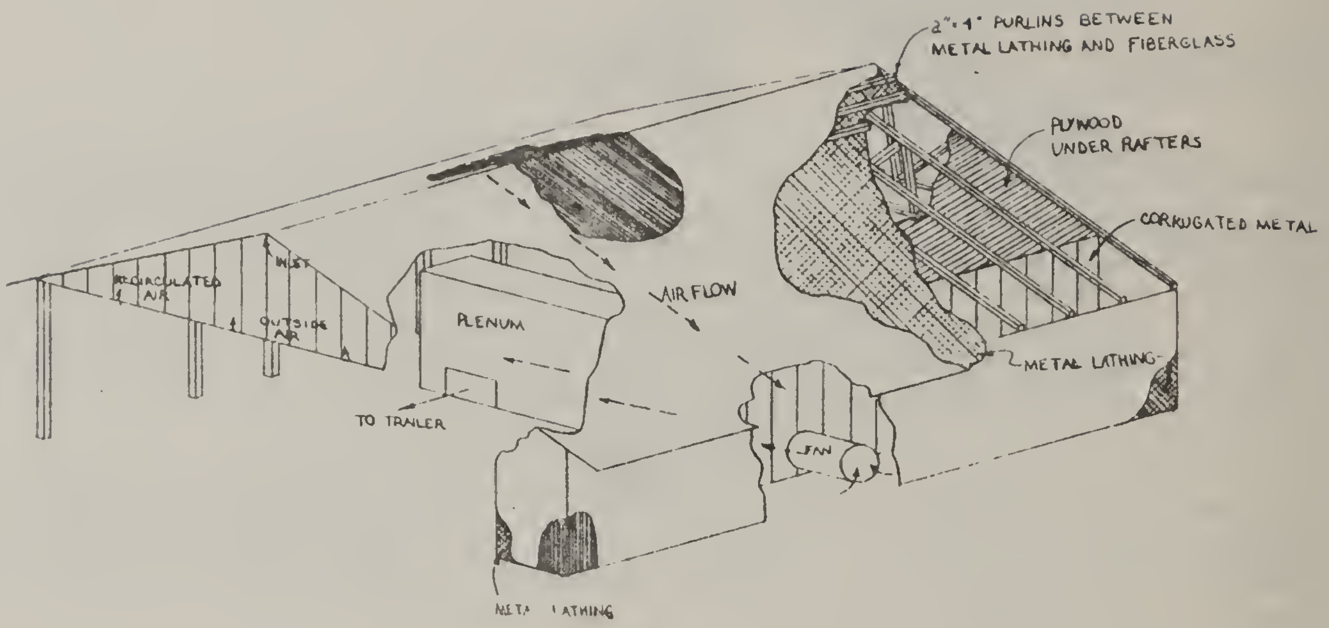
THE COLLECTOR

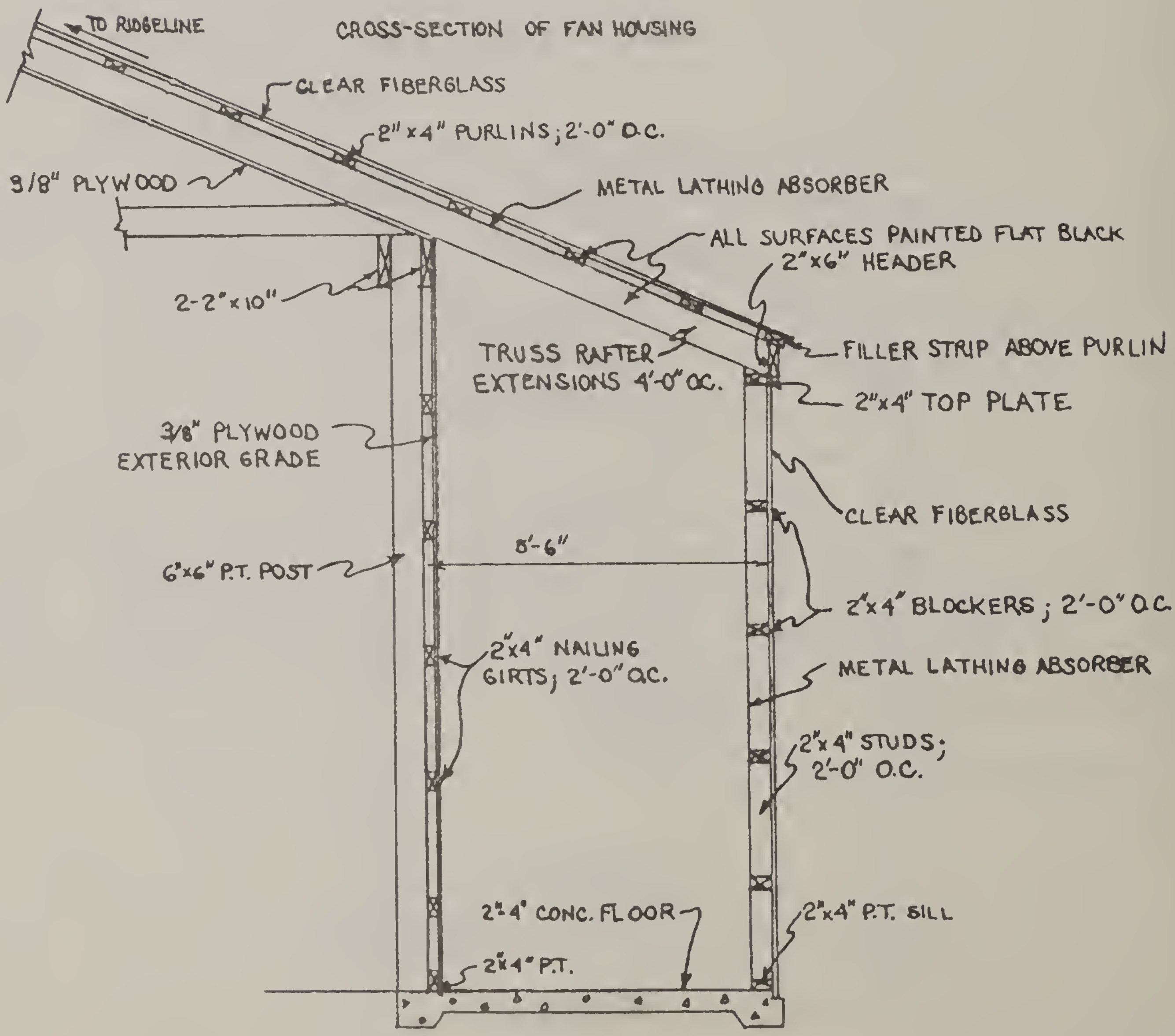
A 1,224 sq. ft. covered-plate collector will be constructed on the south roof of the drying facility and on the roof of an adjacent collection area. An additional 603 sq. ft. of collector will result from the end walls and the vertical south wall of the air collection area.

The roof collector consists of a clear corrugated fiberglass cover over a flat black 3/8" exterior grade plywood absorber. A black expanded metal lathing located in the air channel between the plywood and the fiberglass will provide an additional absorber. A flat black 3/8" exterior grade plywood wall interfaces the collection area and the drying shed.

The air inlet to the collector is located underneath the ridge of the drying shed to allow partial recirculation of the drying air. The drying air should recieve heat from the absorbers as it is drawn down the slope of the roof. The preheated air is then brought into the collection area where it enters the drying unit. The drying unit pulls the air into a plenum which leads to drying trailers. Approximately 30,000 cfm of air will move through the collector at 1" of static pressure.

The total estimated cost (including labor) of the 1,837 sq. ft. solar collector is $3,292.00, or $1.80/sq. ft. The collector is expected to save Mr. Velicky 19% of the energy normally required to dry his crops (a savings of 570 gallons of LP gas annually).


2"×4" PURLINS BETWEEN METAL LATHING AND FIBERGLASS
PLYWOOD UNDER RAFTERS
CORRUGATED METAL
RECIRCULATED AIR
OUTSIDE AIR
PLENUM
AIR FLOW
METAL LATHING
TO TRAILER
FAN
METAL LATHING


TO RIDGELINE
CROSS-SECTION OF FAN HOUSING
CLEAR FIBERGLASS
2"x4" PURLINS; 2'-0" O.C.
3/8" PLYWOOD
METAL LATHING ABSORBER
ALL SURFACES PAINTED FLAT BLACK
2"x6" HEADER
2-2"x10"
TRUSS RAFTER EXTENSIONS 4'-0" O.C.
FILLER STRIP ABOVE PURLIN
2"x4" TOP PLATE
3/8" PLYWOOD EXTERIOR GRADE
CLEAR FIBERGLASS
8'-6"
6"x6" P.T. POST
2"x4" BLOCKERS; 2'-0" O.C.
2"x4" NAILING GIRTS; 2'-0" O.C.
METAL LATHING ABSORBER
2"x4" STUDS; 2'-0" O.C.
2"4" CONC. FLOOR
2"x4" P.T. SILL
2"x4" P.T.

Farmer: Kermit Francis
Rt. 1, Box 491
Boykins, Virginia 23827

THE CROPS

The typical crops grown by Mr. Francis include 350 acres of corn, 225 acres of peanuts, and 50 acres of soybean. Mr. Francis usually dries 35,000 bushels of corn in September, followed by 675,000 pounds of peanuts in October and early November, and 1,250 bushels of soybean in the last half of November. The energy required to dry these crops is estimated to be 538.0 million BTU's (eqivalent to 5,978 gallons of LP gas).

Previous practices utilized five 18 foot diameter bins with LP gas drying units. In order to reduce the high labor requirements found in the in-bin drying of peanuts, a 50' by 48' 8-trailer drying facility (ridge line runing east-west) with an LP gas drying unit will be constructed in 1981. A solar collector will be added to the drying facility''s structure in order to preheat the ambient air before it is drawn into the LP gas drying unit.

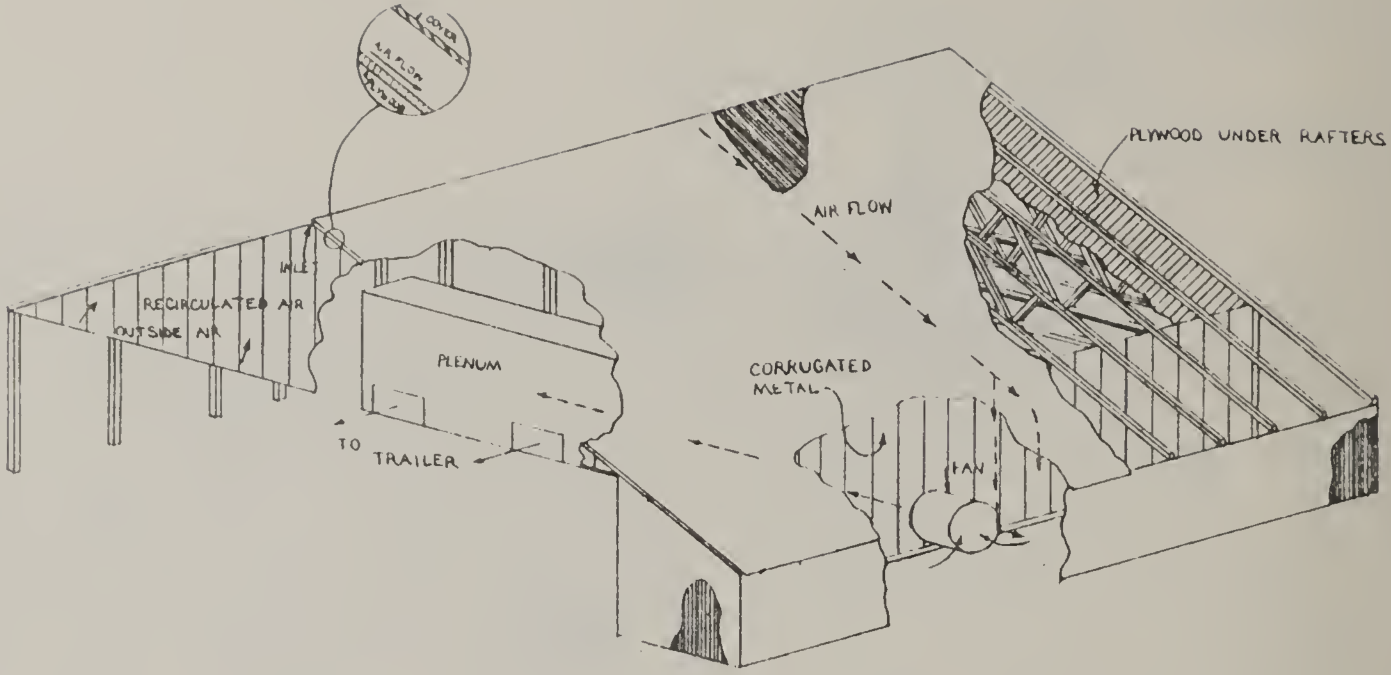
THE COLLECTOR

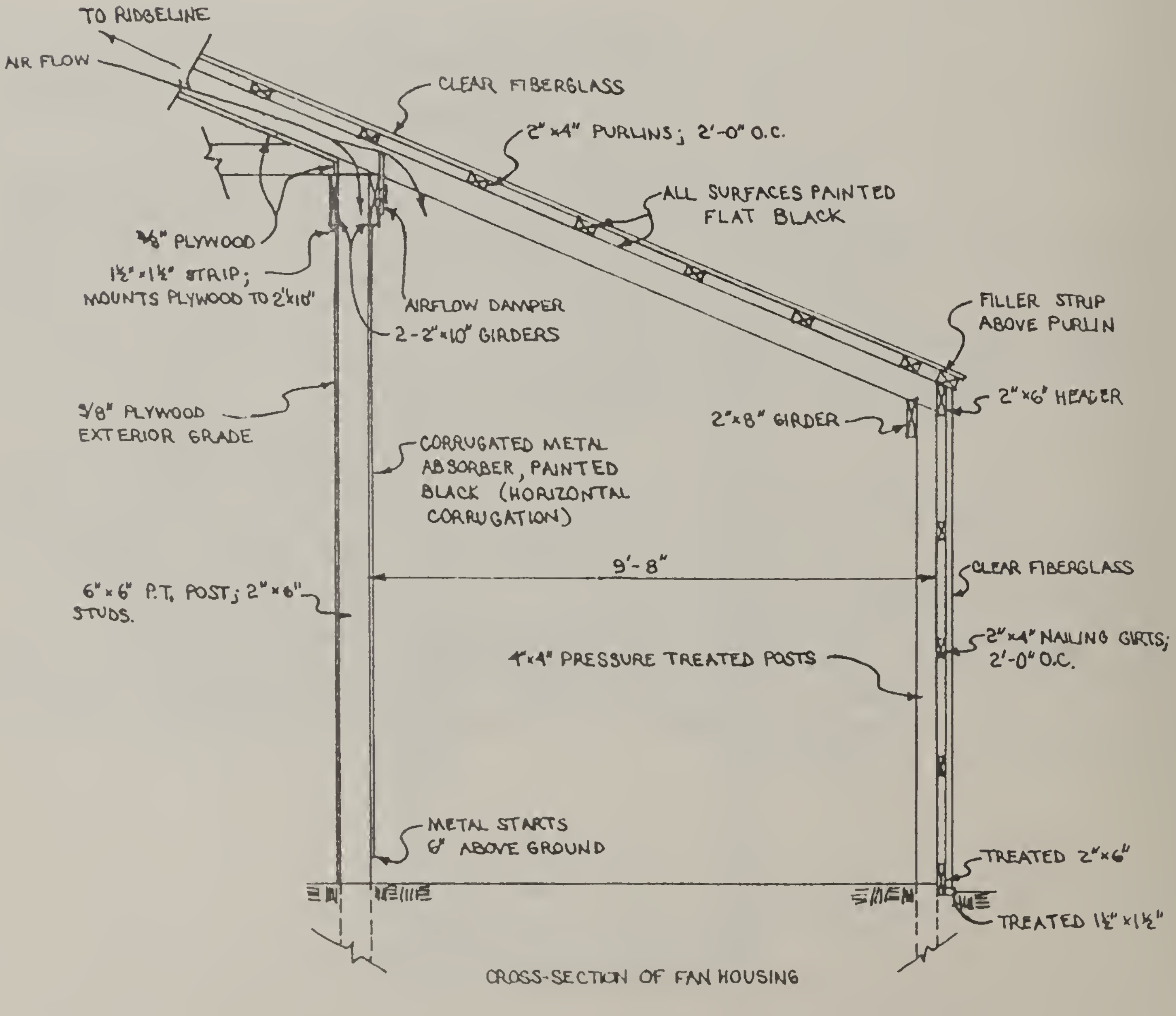
A 1,825 sq. ft. covered-plate solar collector will be constructed on the south roof of the drying shed and on the roof of an adjacent collection area housing the fan. An additional 593 sq. ft. of collector is attributed to the endwalls and the vertical south wall of the collection area.

The roof collector consists of a clear corrugated fiberglass cover over a flat black 3/8" exterior grade plywood absorber. The cover plate on the outer walls and roof of the collection area will be constructed of the same corrugated fiberglass. An additional absorber in the collection area will be a corrugated metal sheathing extending down to 6" above the ground line and separated from the drying facility wall by a 6" air channel.

The air inlet will be located underneath the ridge of the drying shed to allow partial recirculation of the drying air. A portion of the air entering the collection area will be directed by an adjustable damper so that it passes over the corrugated metal absorber before mixing with the air in the collection area. The preheated air will be forced by the fan into a plenum and then into drying trailers. Approximately 30,000 cfm of air will be moved through the collector at 1" of static pressure.

The total estimated cost (including labor) for the 2,418 sq. ft. of solar collector is $3,333.00, or $1.38/sq.ft. The collector is expected to save 16% of the fuel normally required to dry Mr. Francis' crops (a savings of 956 gallons of LP gas annually).





CROSS-SECTION OF FAN HOUSING

Farmer: William Edwards
Rt. 3, Box 39
Windsor, Virginia 23487

THE CROPS

Crops grown at Mr. Edwards' farm site include 175 acres of peanuts, 260 acres of corn, 225 acres of soybean, 120 acres of wheat, 120 acres of barley, 10 acres of oats and 20 acres of milo. Typically Mr. Edwards harvests 4800 bushels of wheat, 6300 bushels of barley and 600 bushels of oats in June. In late August and September 23,400 bushels of corn are harvested, followed by 586,250 lbs. of peanuts in October. A 5,625 bushel crop of soybean along with 1400 bushels of milo are harvested in November.

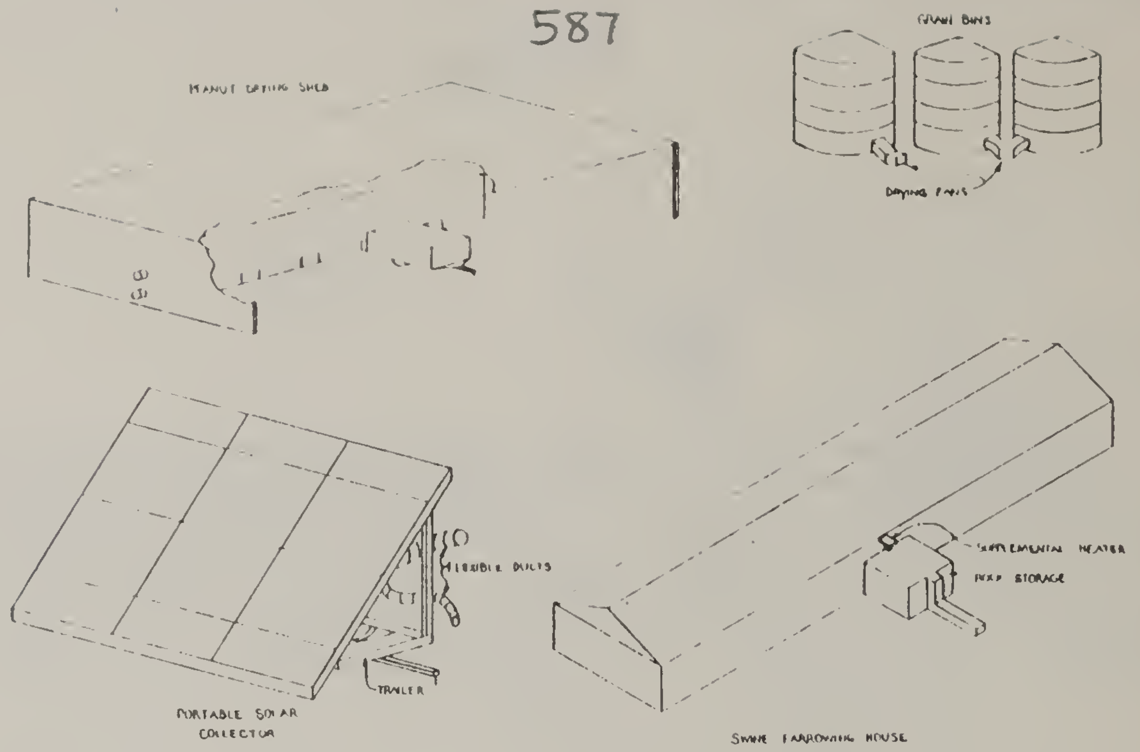
An estimated 723.1 million BTU's of energy (equivalent to 8,034 gallons of LP gas) is required to dry Mr. Edwards' crops. Mr. Edwards uses one 21' diameter and two 18' diameter grain bins, along with a 9 trailer drying shed for the drying shed.

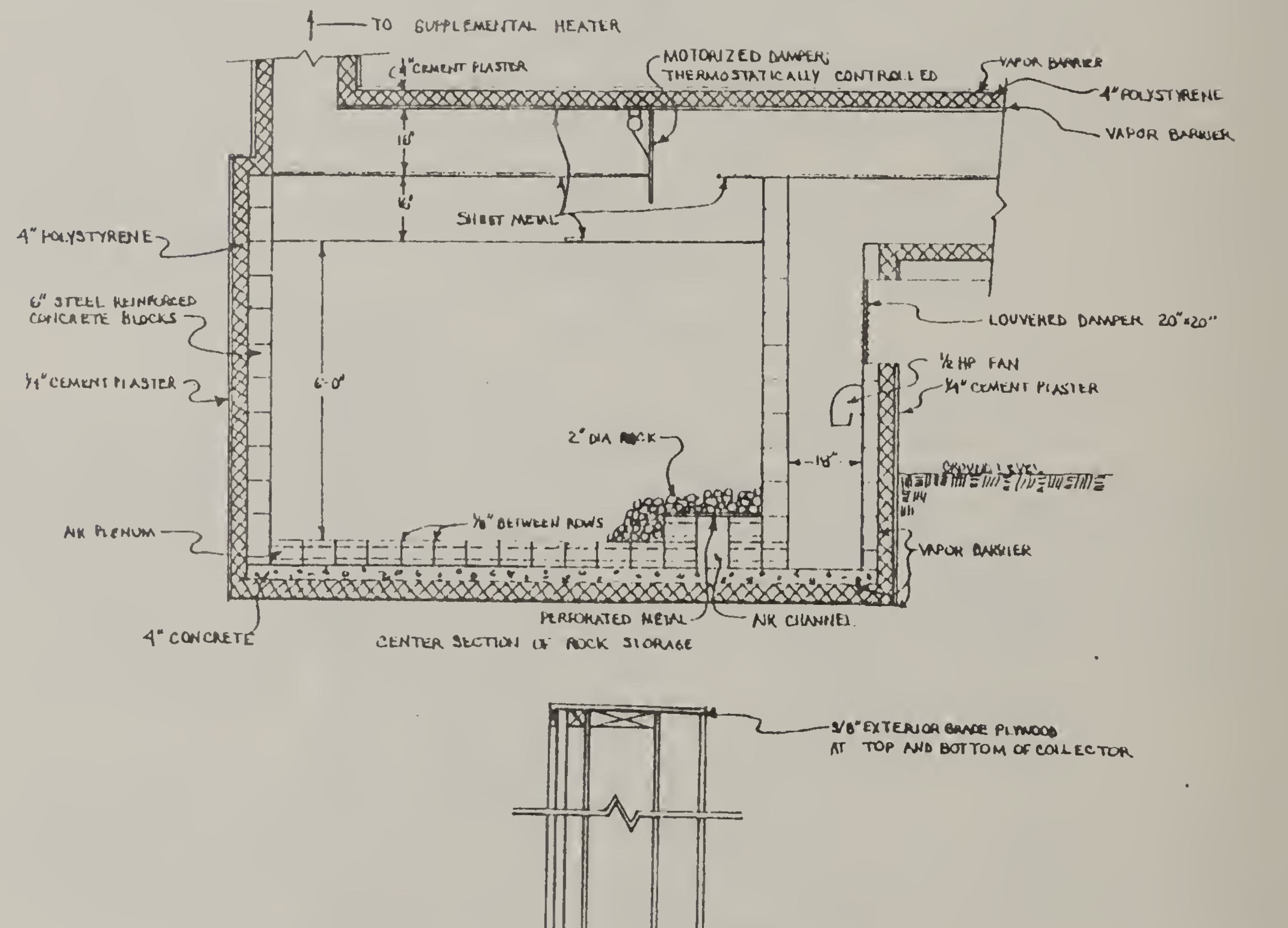
A 24' x 100' 24 crate swine farrowing house is also located at the farm site. An estimated 103.7 million BTU's (equivalent to 1,152 gallons of LP gas) is required annually for heating the farrowing house. In order to reduce the amount of fossil fuel required for crop drying and swine heating, a portable solar collector and rock storage system was designed to preheat the air entering the drying and heating units.

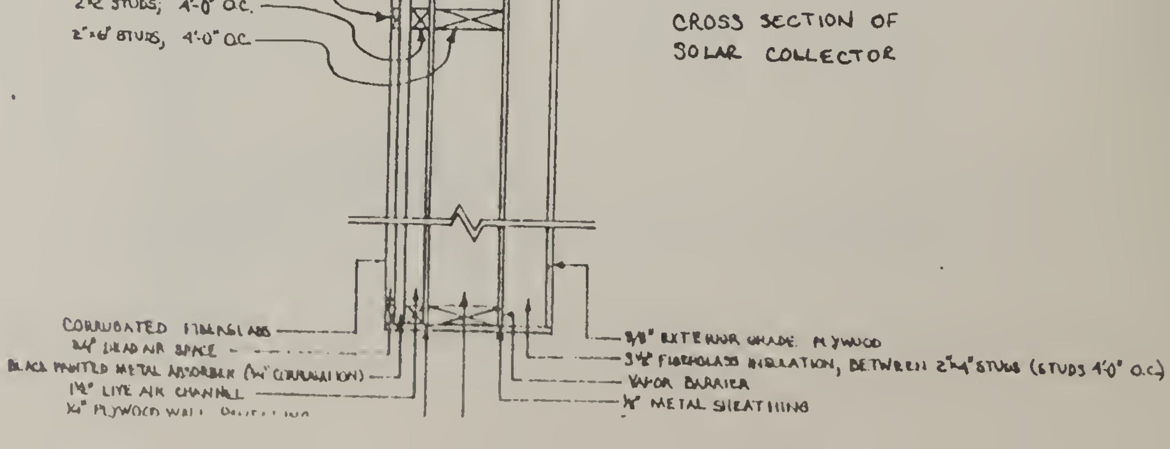
THE COLLECTOR

An 864 sq. ft. (24' x 36') portable suspended plate solar collector will be mounted on a 9'-10 1/2" x 38' trailer chassis. Flexible ducts from the collector can be connected to the bin or trailer drying units or to a rock storage located near the farrowing house. A concrete structure will enclose 30 tons of 2" diameter railroad ballast designed to accumulate energy to be used for swine heating. Air flow through the collector is designed for 12,000 cfm during crop drying and 2,500 cfm for charging the rock storage.

The total estimated cost (including labor) for the 864 sq. ft. collector and 30 ton rock storage unit is $5,912.00, or $6.84/sq. ft. The potential annual savings for crop drying and swine heating is 737 and 600 gallons of LP gas, respectively. This represents a 9.2% and 52.1% reduction of fossil fuel requirements for crop drying and swine heating, respectively.







CROSS SECTION OF SOLAR COLLECTOR

Farmer: Roger Winn
Rt. 1, Box 18
Axton, Virginia 24054

THE CROPS

Crops grown by Mr. Winn include corn, milo, soybean, wheat, oats, and tobacco. The farm size is 540 acres. In a drying period extending from mid-June to December, Mr. Winn typically dries 8,000 bushels of corn, 7,500 bushels of milo, 2,500 bushels of soybean, 2,750 bushels of wheat, 2,000 bushels of oats, and 60,000 lbs. of tobacco. The energy required to dry Mr. Winn's crops is estimated to be 859 million BTU's (equivalent to 9,948 gallons of LP gas).

The grain crops are dried using an in-bin drying facility. Two sets of bins (two bins per set) are equipped with drying fans and LP gas burners. In 1980, a covered-plate solar collector was constructed in the attic of the farm shop. The attic collector is used to preheat the drying air for one set of grain drying bins.

The tobacco is cured in three conventional bulk curing barns (each barn has 3,000 lbs. of curing capacity). A breakdown of Mr. Winn's energy requirements has shown that 80% of the energy required per year is used to cure tobacco. In order to reduce the amount of fossil fuel required for tobacco curing , a solar collector and water storage unit will be constructed.

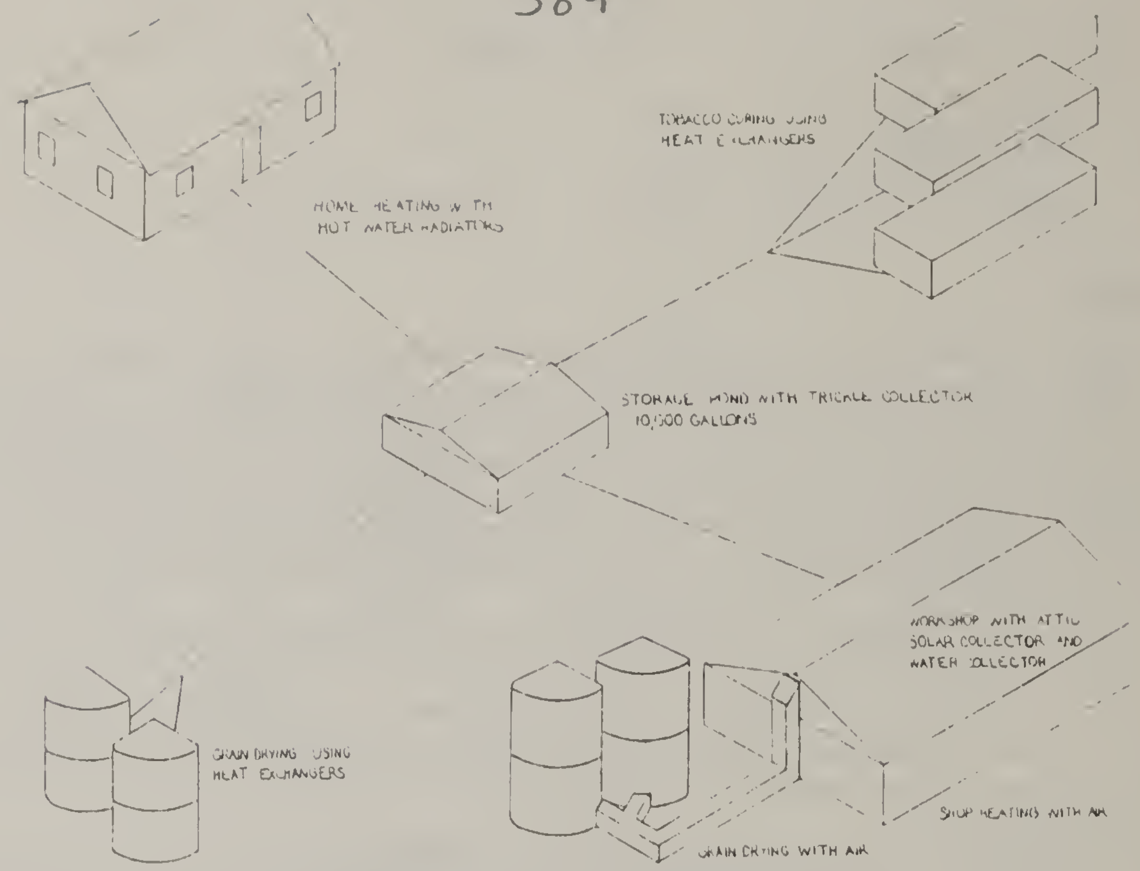
THE COLLECTOR

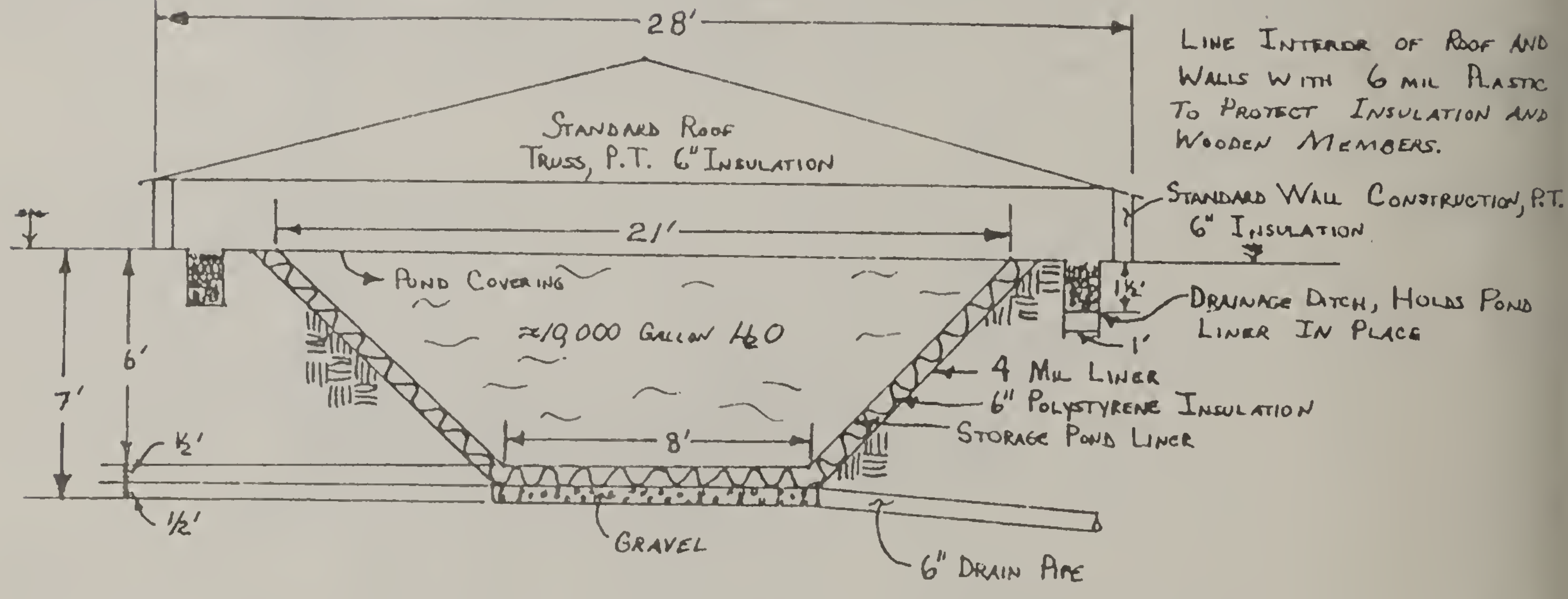
A 600 sq. ft. solar water collector will be placed above the plywood absorber of an existing covered-plate collector, located over the farm shop. An additional 336 sq. ft. trickle collector will be constructed on the roof of a structure to enclose a 10,000 gallon lagoon storage pond. Water from the storage lagoon will run down the roof slope between a corrugated metal absorber and a corrugated fiberglass cover. Water can be circulated to the collectors from the storage pond whenever temperature controllers indicate that an energy gain is possible.

The energy stored in the pond water will be used to heat air for tobacco curing and grain drying operations. Heated water will be circulated to water-to-air heat exchangers whenever temperature controllers indicate that the storage pond is warmer than the ambient air.

In the future, the storage pond may be used as a supplemental heat source for Mr. Winn's oil-fired hot water home heating system (not to be cost shared).

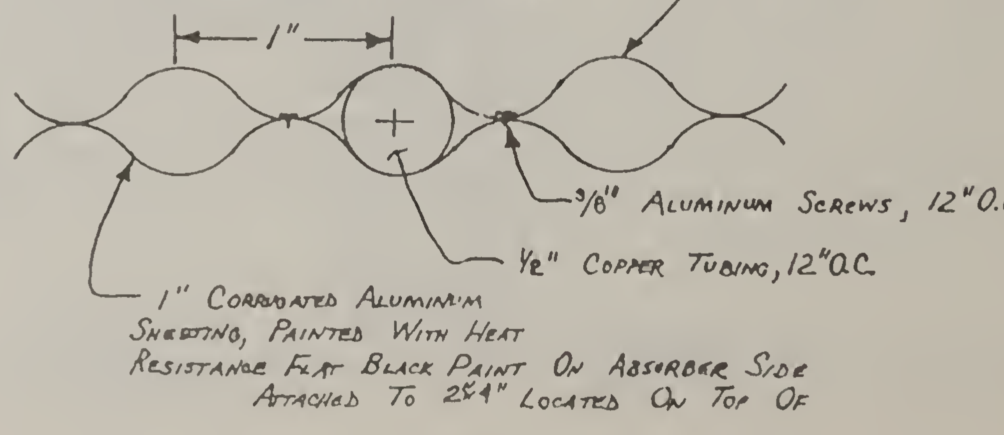
The total cost (including labor) for the 936 sq. ft. of collector and water storage is approximately $12,000.00, or $12.82/sq. ft. This cost includes the construction for adaptation to the home heating system, as well as the tobacco curing system and the grain drying system. The potential savings for tobacco curing has been estimated to be 1,700 gallons of LP gas annually; this represents 21% of Mr. Winn's tobacco curing cost. Other savings are expected from grain drying and home heating applications.

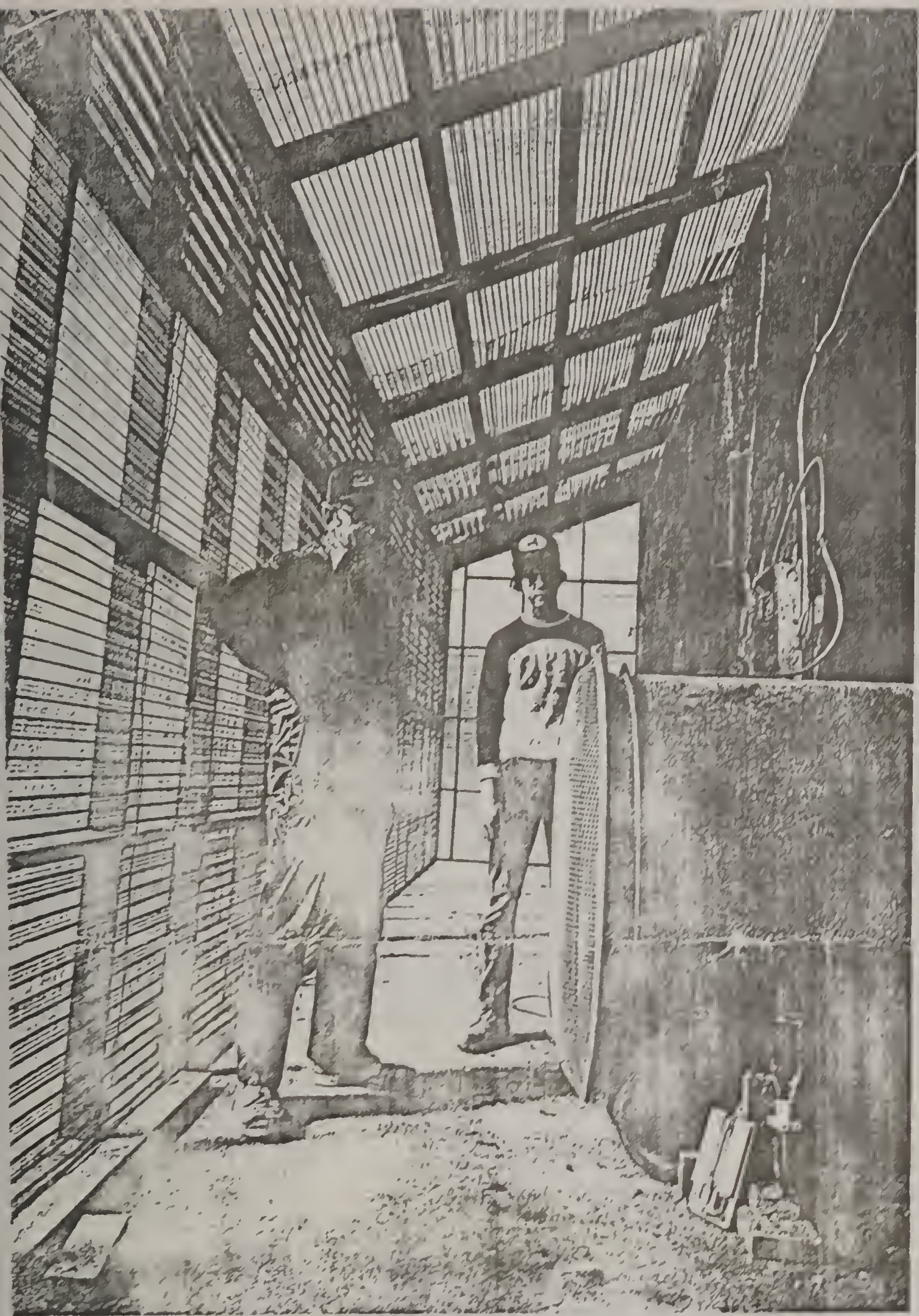




STORAGE POND

WATER COLLECTOR





Ben Veliky (left) and his son Stewart in their solar collector room. Most surfaces in this room are painted black for better heat absorption.

Sun Power Cuts Peanut-Drying Costs

The sun's heat saves curing costs for Ben Veliky of Emporia, Va. Two years ago, Veliky had a solar collector built as part of his new drying shed. A plywood air chamber carries heat gathered by the unit into trailers full of peanuts under the shed.

The collector is a supplement to the conventional gas-fired heater that delivers hot air to the trailers through the same duct.

"I'm very much interested in insulation and all types of energy saving," says Veliky. "So when I heard about solar drying, I figured it would pay for itself."

A. J. Lambert, Extension agricultural engineer at Virginia Tech (VPI), agrees that the solar unit saves money. But he cautions that the amount it saves depends on how it's used, how often, and when.

"The amount of energy the unit collects is based on the number of clear days you have," Lambert explains. "Of course, it collects some heat even on a cloudy day but not nearly as much as on a clear one." At curing time last year, Veliky's area averaged about five sunny or mostly sunny days out of seven

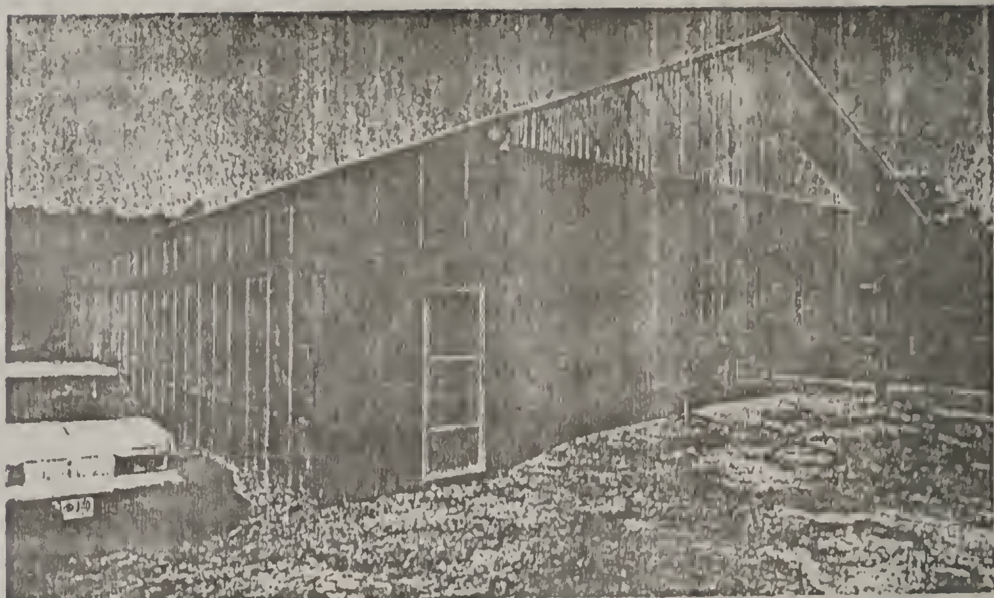
Lambert says the 1,800 square feet of collector (including roof and walls of the collector room as well as the partial fiber glass roof of the shed) saves Veliky, in round figures, at least 16 gallons of LP-gas per clear day and an average of 80 gallons per week. That's a conservative estimate. A similar unit in the area saved its owner 589 gallons of the fuel in five weeks, Lambert reports. And Veliky took pains to make his unit as airtight as possible.

"At Tech, we've been saying that it takes four to five years for a collector like this to pay for itself in fuel savings," says Lambert. "But that depends on how much it costs to build and how much you use it."

Cost of building such a collector will be \$2 or less per square foot, according to Lambert. That includes surface area of both the collector room and the fiber glass roof on the shed. So a collector like Veliky's should add no more than \$3,600 to the cost of a drying facility.

Energy tax credits as an extra investment credit also ease the financial burden of constructing a unit. "If you have a good crop year and are making money, these credits should apply," Lambert says. "But in a poor crop year like the past one, you can't

The roof of the collector room follows the line of the shed roof. Sides and roof of the room collect heat. Lambert says the slope of this roof is a compromise to take advantage of the most heat when Veliky needs it—mid-August to mid-November—for drying peanuts. In summer, a flatter roof would take in more radiation. In winter, a more vertical roof would absorb extra heat.



take advantage of them." Veliky received ASCS loans to finance the collector, the air duct, and his new drying trailers.

Multiple use is another factor. When it's not drying peanuts, the fiber glass-walled collector room can be fitted with shelves and used as a greenhouse. It can also heat something besides the drying shed.

"I had planned to use the same solar collector to supply heat to a farrowing house," Veliky recalls. "But the collector is too close to my house. The odor from that many extra hogs here would be too much for my family and neighbors."

Area farmers use their solar units for drying grain and even curing wood when peanuts aren't being dried.

Drying peanuts at a low moisture content is less efficient than when moisture is high. So the lower the moisture level of the peanuts, the higher the percentage of gas this solar collector saves, according to Lambert. *Karl Wolfshohl.*

In this drying shed, trailers are backed in from each end and hooked to the central air duct. The shed is supported by poles along two sides, but there are no poles at the ends or in the middle to interfere with trailer movement.

How This Unit Is Made

Veliky's solar collector is built directly onto the south side of his clear-span, truss-roofed drying shed, where it will catch all possible sunshine. The 7- x 50-foot collecting room runs the length of the shed. Solar panels are used on the south-sloping side of the shed's roof in place of conventional corrugated metal.

Where possible, surfaces in the collecting room and under the roof panels are painted flat black for better heat absorption.

All panels are greenhouse-grade corrugated fiber glass treated for protection against ultraviolet light. These panels cover black metal lathing, which serves as an extra heat absorber. This is the same type of lathing used as support for plaster.

To make it more efficient, Veliky took care to make his solar collector airtight. To do this, he caulked junctures where fiber glass panels join and where the collector walls meet the floor or shed wall. A storm door at the entrance can be propped open in summer to prevent damaging heat buildup when the unit isn't in use.

A fan blows hot air from the collector through a plywood duct into trailers that are backed to the duct from both ends of the clear-span shed. The fan and a conventional gas-fired heater comprise a unit.

The shed will accommodate three trailers from either end. Absence of poles except on the sides of this clear-span unit makes backing the trailers easy.

Lambert and Veliky are experimenting with a partial return of air to the collector room after it has passed through the peanuts. They're testing the use of curtains along the shed's open sides to trap the warm, moist air and reuse part of it. So far, the curtains or total enclosure isn't included in VPI's plans for building the unit. The curtains have presented some tough problems with moisture condensation. The solar collector and clear-span shed, however, are proved performers.

You can get plans for building both the solar collector and the clear-span peanut drying shed from Plan Service, Agricultural Engineering Department, VPI&SU, Blacksburg, VA 24061. For more information about the unit, call Andrew J. Lambert at 1-703-961-6089.

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ON-FARM ENERGY
FOR CROP DRYING

Cuts fuel bills 15% to 60%

By HARRIS BARNES JR.

Photos by ...

A BIO-MASS FURNACE burns big round bales of cornstalks, small grain straw and other crop residues to save between $3,500 and $4,000 for Frank and Ritchie Jordan, Suffolk, Va. They also like to burn wood.

A MOBILE TWO-STAGE WOOD BURNER (top photo) supplies enough heat to dry 60% of Harold Owen's crops in Southampton County, Va. The gasifier, or second stage, reaches 2,000°F, so he heats water that runs through four old car radiators.

■ Crop-dryer fuel bills dived in 1981 for farmers who tried on-farm energy sources, with engineering help from A.J. Lambert, Virginia Tech Extension agricultural engineer, Blacksburg, Va.

Armed with cost-sharing funds from the U.S. Department of Energy (DOE), Lambert worked with farmers in designing bio-mass and solar drying systems, then helped them step up dryer efficiency.

Frank and Ritchie Jordan, Suffolk, Va., say their commercially built Stormor Bio-Mass furnace (photo, left), coupled with the drying system they designed with Lambert, saves $3,500 to $4,000 a year in drying fuel costs for their 200 acres of corn and 150 acres of peanuts.

They expect the system to pay off their share of the dryer investment—$7,200—in two to three years.

Next to the furnace, the Jordans put 100 tons of rocks into a heat storage and stabilizer system. This lets them draw off heat at crop-drying temperatures around the clock, and works especially well for peanuts where heat must not exceed 95°F.

The Jordans charge their furnace by unloading 500-lb. bales of cornstalks and crop residue into it with a front end tractor loader.

One bale lasts about four hours, so the Jordans like wood, especially at night because it burns longer.

"We need eight hours of sleep," says Frank. "With wood, we don't have to get up for that two o'clock feeding every morning."

Harold Owen, Southampton County, Va., paid for all of his mobile two-stage, wood-burning crop dryer—$8,000 (photo above). Last year he used only 1,400 gal. of LP gas—enough to dry 40% of his crops, principally corn and peanuts. "The other 60% we dried with heat from on-the-farm scrap timber—cut, hauled and stacked by on farm labor," says Owen. "Both the wood and the labor needed a job to do."

In Owen's two-stage furnace, the wood is consumed in the primary stage. In the second, or gasifier stage, gases burn at temperatures that can reach 2,000°F.

"After start-up, there's practically no visible smoke," says Lambert.

To modify the high temperatures for crop drying, Owen runs 500 gal. of water through jackets over the furnace, then pumps the hot water into four old car radiators and pulls air through the radiators with fans.

Owen compared conventional dryer results with his new system. "The hot water setup dries just as fast, or faster, than the LP gas system," says Owen. "In fact, many nights I was getting 3° to 4° more heat rise from the radiators than from the conventional system."

To step up efficiency in his wood-burning hot-water system, Owen is using stainless steel to insulate and protect his furnace door and air delivery pipe. He's also insulating water lines, water tanks and the burner itself. But he wants to keep the burner mobile, "so I can dry any crop, or roll it to the shop, or even the house, if need be."

Engineer Lambert says Owen's system is about 70% efficient and improving. "The high-pressure air supply overheated and cracked, last year," he says. "The burner needs turbolators in the fire tubes and an induced draft in the stack."

With his half-million BTU burner, Owen gets a 20° to 40° heat rise when drying corn. "With help from a stirring device, I intend to dry high-moisture corn all the way this year," says Owen. "I hope to get the corn out earlier, when the weather is with me, not against me."

Lambert says the figure tossed around for the cost of wood for drying is $15 a ton, but both the Jordans and Owen say they use available labor and scrap timber, and that's a lot different than laying out 70¢ to 75¢ a gallon hard cash for thousands of gallons of LP gas fuel.

Although initial costs of a biomass furnace are somewhat higher than most solar collectors, Lambert feels that burning wood or crop residues may offer more flexibility and be more dependable for crop drying over the years than solar heat.

"We try not to oversell solar heat for crop drying, partly because we never know when we might get a rainy season," he says. "But a good system does work when the weather is right."

William "Pete" Edwards, Isle of Wright County, Va., says his portable solar collector (photo, upper right) cut his LP gas bill by 15% to 20% last year.

To store heat for night-time and rainy weather use, he's building a rock bed beside his 80-sow farrowing house. Besides providing 60% to 70% of the heat needed for the farrowing house, the solar collector also dries small grain, corn, milo, peanuts and soybeans for Edwards.

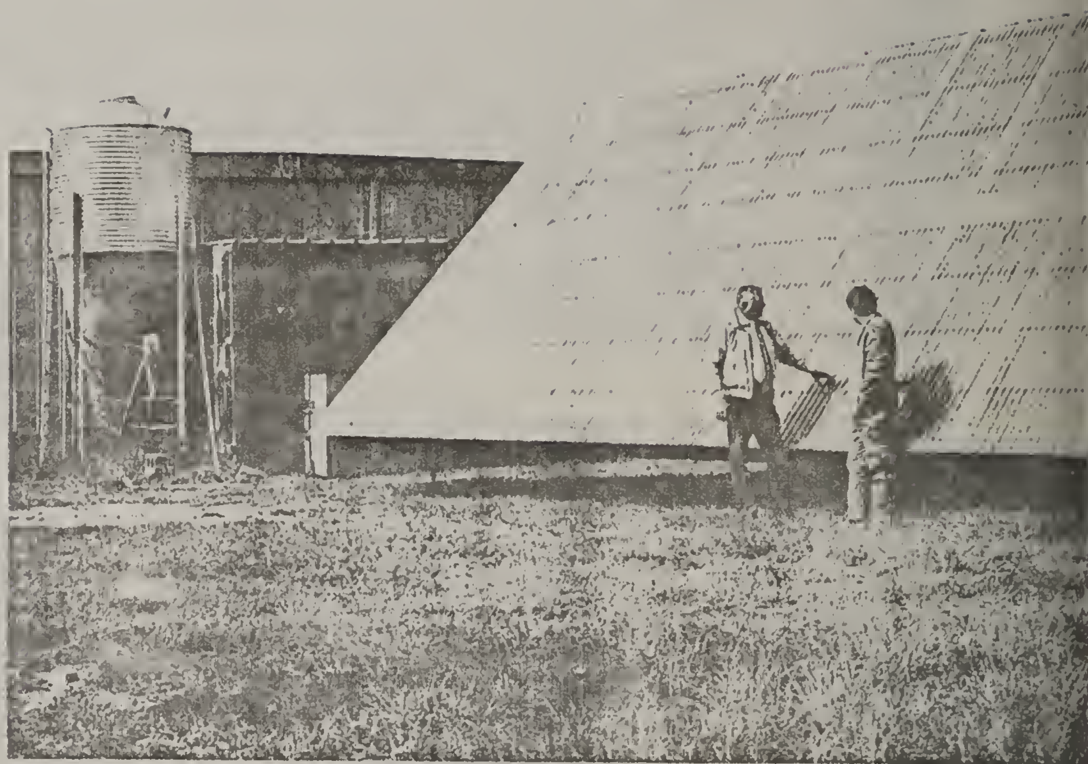
He built his 20'x45' collector on a mobile home frame for about $5,000, with DOE funds paying half the cost.

"I don't plan to enlarge it, because I want to keep it mobile and versatile," says Edwards. Solar heat saves him about 600 gal. of fuel a year on the farrowing house alone.

In Southampton County, Va., computer data show that a solar collector Kermit Francis built as part of a new building cuts his crop-dryer fuel bills by 16% (photo, right). During a single week when Lambert had the system under test, Francis cut LP gas use by 30%.

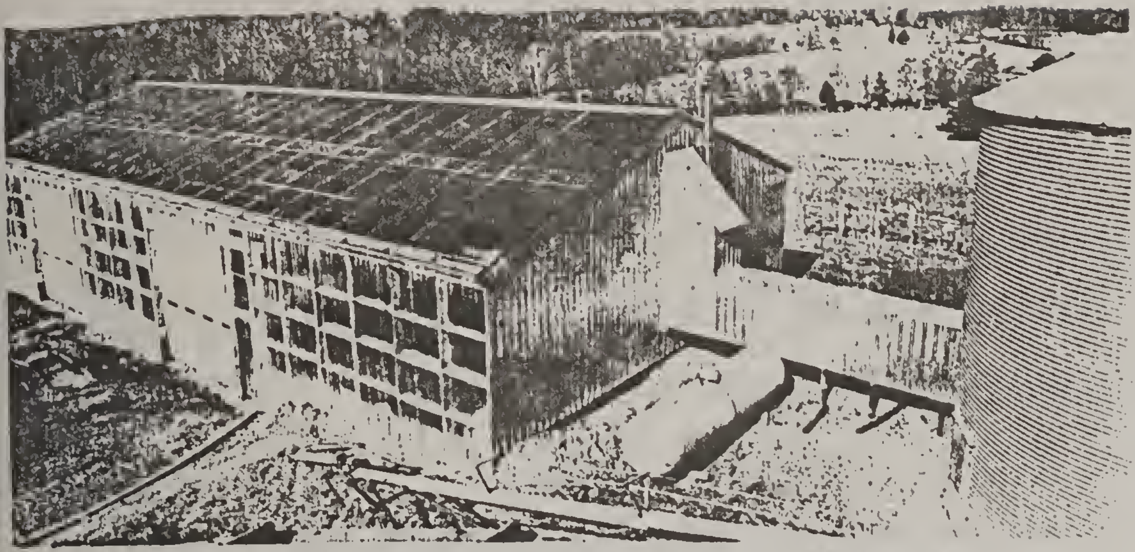
Working with Lambert, Francis also got the DOE to share half the cost—$1,700—for the solar collector on his new building.

Lambert used a transit to position the new building so that the solar-heat collection room faces due south, as does part of the building roof, which also traps the sun's rays. Fans pull air from under the roof into the heat collection room, then direct it into the crop dryer. ◁



A MOBILE SOLAR COLLECTOR cuts LP gas bills 15% to 20% for William Edwards when he dries small grain, corn, milo, peanuts and soybeans in Isle of Wight County, Va. In winter, he moves it to help heat his 80-sow farrowing house.

WHACKS 16% OFF LP GAS COSTS. Two 7½-hp. fans (below) move air from a solar-heat collection room for Kermit Francis, Southampton County, Va. He built the collector room with low-cost fiberglass panels that were "seconds."



Solar-heated air that collects in the attic of this farm shop is ducted directly to conventional fans on these grain bins. The Winns will add ventilator fans to the building roof to vent damaging heat from the attic in summer.

"We Never Turned On the Propane"

Solar heat cut fuel bills and improved grain quality for these farmers.

The attic of a new farm shop doubles as a heat source to dry grain for Dogwood Farm at Axton, Va. Roger Winn and his sons Roger, Jr., and George built the 3,200-square-foot structure with some modifications that converted it to a solar heat collector.

The Winns dried two bins of grain with hot air from the unit in 1980. While one year's test doesn't give a complete evaluation, they believe the unit will make propane heat almost a thing of the past in their six storage bins, which total 20,000 bushels of capacity. And the newfangled drying unit also improved grain quality last year.

"Last fall, we never turned on the propane heating unit in the two bins that were hooked to solar heat," says Roger Winn. "But we're gaining in more ways than just saving fuel," he points out. "We dry our grain in the bins, since layer drying isn't practical for our operation.

"I've never been able to adjust the propane burner down enough to keep from cooking some corn at the bottom of the bins while grain higher up is drying. Since the solar-heated air is at a lower temperature than the propane heat, it won't damage the bottom grain other than drying it out more than that at the top.

Most wood surfaces in this attic are painted flat black for better heat absorption. To stretch the black latex paint, the Winns cut it with equal parts of water.

Their solar unit is simple. The shop roof is covered with greenhouse-grade fiber glass sheets instead of conventional sheet metal. On the underside of the trusses, the Winns added a ceiling made from quarter-inch plywood. Then they used flat black paint on virtually all wood surfaces in their new attic for better heat absorption.

A sheet metal duct connects this attic directly to the fans on their nearby storage bins. The fans draw heat from the attic and feed it into the stored grains.

The attic and junctures between ducts and fan unit are well sealed, so the fans draw in as little cool, outside air as possible.

The east wall of their shop is also covered with the fiber glass panels. These provide both extra heat and light. Large doors in the shop can be opened to prevent excessive heat buildup where the Winns work. Two fans in the ceiling draw air from the lower part of the shop and blow it into the attic. Conversely, the Winns can reverse direction of the fans so that they blow heat downward either to heat the shop in winter or to prevent damaging heat buildup in the attic in summer. The fans kick on automatically according to a thermostat setting.

Agricultural engineers at Virginia Tech designed this system for the Winns and are watching it closely.

A. J. Lambert, a Virginia Tech ag engineer, estimates cost of a solar collector to be about $2 per square foot of collector area. Federal energy credits, in addition to usual investment credits for farm structures, help make solar units and some other new-style energy-saving systems an attractive investment.

The Winns have more plans for solar power. When there's no grain to be dried, they may route heat from their collector to three bulk tobacco barns.

"We can use this collector in July and October for grain drying," says the elder Winn. "If we can also use it in August and September for tobacco, it will be that much more practical."

The three may opt for a whole new collector that involves heating water, and then routing that heated water into the bulk barns. The water would give them heat storage, which the heated air system doesn't provide.

Lambert encourages owners of solar collectors to use a unit for as many different heating jobs as possible, from curing tobacco to heating a home or hog house. This spreads the cost of one unit and gives the owner faster return on investment.

Karl Wolfshohl.

News Article
Ernest Wrenn
December 14, 1981

"I was really pleased with the money we saved in fuel costs this fall with our new solar drying system," commented Kermit Francis recently. "I was also amazed how fast we were able to dry peanuts with the unit."

Kermit and his son Glenn who farm near Capron secured James Vick, a local contractor, to construct the building which can handle eight drying trailers. He gave them one fine job.

"The drying unit which the Francis' have is probably the best of its kind in the state" says A. J. Lambert, Va. Tech Extension Agricultural Engineer. "They incorporated all the features we feel essential for maximum efficiency to utilize the sun's ray to dry crops and for other uses."

Lambert continued, "Unfortunately for some reason we have difficulty in getting most farmers to agree to go all the way with our recommendations when building solar or other types of energy saving units. They want to change one or more features which often results in the unit not performing at maximum efficiency."

The Francis' building designed by Lambert is constructed so the air intake to the collector is on the underside of the roof along the peak. The air travels down the southside between clear corrugated fiberglass panels nailed on top of the rafters to 2 x 4 purlins. Plywood is attached underneath forming air channels down the roof. The area of the rafters, purlins and plywood exposed to the sun are painted black to absorb the solar energy. Also black metal lathing installed just under the fiberglass panels improves further the efficiency of the collector in trapping the sun's rays.

The heated ~~bar~~ air then comes off the roof drawn by the drying fans into a sort of greenhouse on the southside of the building made of the corrugated fiberglass

panels. Here the air picks up more heat then is pulled into the air tunnel (plenum) by the two 7½ HP stacked fans. The solar heated air is forced down the air tunnel and out through the drying trailers.

Kermit and Glenn dried 636,299 pounds of peanuts in their eight trailers this fall. In addition they dried four trailer loads for a neighbor. According to their records, the cost was 49 cents per hundred weight for propane gas to dry peanuts.

Kermit commented, "This system really provides a lot of air to dry with. Even when we had all trailers attached you could place a handkerchief on top of any load and the air coming out of the trailer would lift it right up."

I wondered if their peanuts might have dried too fast with the rapid turn around of the trailers. I asked Windell, Kermit's wife, to check out their grade sheets looking at the per cent of sound splits. She reported the average was less than 2%. This was good. We don't like to see splits exceed the 2% level. If they do, it indicates too rapid drying and lowering of quality.

Lambert said, "We had some instruments monitoring the Francis' unit and checking the efficiency of it. It looks like they were saving around 33% on the cost of fuel to dry this fall."

The Francis' record indicated they used 1.38 KWH of electricity per hundred weight to dry. At 5 cents per KWH, this was about seven cents per hundred weight of peanuts for electricity to dry.

Lambert and his colleagues from Va. Tech monitored two other solar units in the county this year. Both were set up in 1980.

Robert Puliey and son Jeffrey, Ivor, have a six trailer drying building similar to the Francis' unit. It appears they had a savings of around 30% in energy cost this fall, utilizing solar energy to cut down on the use of propane gas for drying.

Richard Cutchins, Black Creek area, with the assistance of Va. Tech Ag Engineers converted one of his drying trailer buildings to utilize solar energy. He told recently, "My cost was much less for propane gas this year to dry peanuts in my drying building equipped to use solar energy. It worked out to 42 cents per hundred pounds using solar heat versus 65 cents per hundred pounds in a nearby drying trailer [redacted] not using solar energy. I'm well pleased with the results."

In Richard's setup the entire existing metal roof is utilized as the solar collector. Air channels were created under the roof by nailing plywood under the rafters. The solar heated air is pulled up these channels between the rafters toward the roof peak into a plywood tunnel which carries the air through the building and down to the big fan on one end.

In addition to drying peanuts, Richard has been drying corn in the unit and solar energy has saved him considerable money in gas to dry corn.

Lambert commented, "With Richard's unit and with the others it's interesting we've found that a lot of the heat coming off the trailers during drying is being salvaged and recirculated right back through the system and used again."

He concluded, "The more farmers use these units the more we can justify the cost of the solar equipment. During the winter if heat can be pulled off the roof to heat a farm shop or some other use, it makes it even more worthwhile to construct solar collecting equipment."

Certainly it appears solar energy has a place on many farmers in the future to cut the cost of expensive petroleum based energy products.

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